E83-10043

AgRISTARS

YM-U2-04289 ~~CR-167240~~
JSC-18236
TM-85167

A Joint Program for
Agriculture and
Resources Inventory
Surveys Through
Aerospace
Remote Sensing

MARCH 1982

Yield Model Development

COMPARISON OF CEAS AND WILLIAMS-TYPE MODELS FOR SPRING WHEAT YIELDS IN NORTH DAKOTA AND MINNESOTA

(E83-10043) COMPARISON OF CEAS AND WILLIAMS-TYPE MODELS FOR SPRING WHEAT YIELDS IN NORTH DAKOTA AND MINNESOTA (NASA) 62 p HC A04/MF A01 CSCL 02C

N83-16807

Unclas
G3/43 00043

RM 200, FEDERAL BLDG.
600 E. CHERRY ST.
COLUMBIA, MO 65201

Lyndon B. Johnson Space Center
Houston, Texas 77058

1. Report No. YM-U2-04287
JSC-18236

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Comparison of CEAS and Williams-Type Models for Spring Wheat Yields in North Dakota and Minnesota

5. Report Date
March 1982

6. Performing Organization Code

7. Author(s)
T. L. Barnett

8. Performing Organization Report No.
YMD-1-4-2 (82-03.1)

9. Performing Organization Name and Address
NASA
Rm 200, Federal Bldg.
600 E. Cherry St.
Columbia, MO 65201

10. Work Unit No.

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
NASA/JSC
Mail Code SK
Houston, TX 77058

13. Type of Report and Period Covered
Technical Report

14. Sponsoring Agency Code
SK

15. Supplementary Notes

ORIGINAL PAGE IS
OF POOR QUALITY

16. Abstract

CEAS
The CEAS and Williams-type yield modelsare both basedon multiple regression analysis of historical time series data at CRD level. The CASE model develops a separate relation for each CRD; the Williams-type model pools CRD data to regional level (groups of similar CRDs). Basic variables considered in the analyses are USDA yield, monthly mean temperature, monthly precipitation, and variables derived from these. The Williams-type model also used soil texture and topographic information. Technological trend is represented in both by piecewise linear functions of year. Indicators of yield reliability obtained from a ten-year bootstrap test of each model (1970-1979) demonstrate that the models are very similar in performance in all respects. Both models are about equally objective, adequate, timely, simple, and inexpensive. Both consider scientific knowledge on a broad scale but not in detail. Neither provides a good current measure of modeled yield reliability. The CEAS model is considered very slightly preferable for AgRISTARS applications.

This research was conducted as part of the AgRISTARS Yield Model Development Project. It is part of Task 4 (Subtask 2) in Major Project Element 1

17. Key Words (Suggested by Author(s))
Model evaluation
Yield modeling
Linear regression

18. Distribution Statement

19. Security Classif. (of this report)
Unclass.

20. Security Classif. (of this page)
Unclass.

21. No. of Pages
61

22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22161

ORIGINAL PAGE IS
OF POOR QUALITY

Comparison of CEAS and Williams-type Models for Spring Wheat Yields in North Dakota and Minnesota

by

T.L. Barnett

This research was conducted as part of the AgRISTARS Yield Model Development Project. It is part of Task 4 (Subtask 2) in Major Project Element 1 as identified in the Yield Model Development Project Implementation Plan dated November, 1981 (YM-J1-C0642, JSC - 17436).

AgRISTARS

Yield Model Development Project..

YMD - 1-4-2 (82-03.1)

Comparison of CEAS and Williams-type Models for Spring Wheat Yields in North Dakota and Minnesota. By Tom L. Barnett; N.A.S.A., Yield Model Development Center, Columbia, Missouri; March, 1982.

ABSTRACT

The CEAS and Williams-type yield models are both based on multiple regression analysis of historical time series data at CRD level. The CEAS model develops a separate relation for each CRD; the Williams-type model pools CRD data to regional level (groups of similar CRDs). Basic variables considered in the analyses are USDA yield, monthly mean temperature, monthly precipitation, and variables derived from these. The Williams-type model also used soil texture and topographic information. Technological trend is represented in both by piecewise linear functions of year. Indicators of yield reliability obtained from a ten-year bootstrap test of each model (1970-1979)) demonstrate that the models are very similar in performance in all respects. Both models are about equally objective, adequate, timely, simple, and inexpensive. Both consider scientific knowledge on a broad scale but not in detail. Neither provides a good current measure of modeled yield reliability. The CEAS model is considered very slightly preferable for AgRISTARS applications.

Key words: Model evaluation, yield modeling, linear regression.

Acknowledgements

The author wishes to thank Wendell Wilson, Clarence Sakamoto, Sharon LeDuc, and Jeanne Seabaugh of the AgRISTARS Yield Model Development Project at Columbia, Missouri for their comments and assistance in preparation of this project.

ORIGINAL PAGE IS
OF POOR QUALITY

Table of Contents

Table of Contents Continued:

ORIGINAL PAGE IS
OF POOR QUALITY

Figures and Tables

ORIGINAL PAGE IS
OF POOR QUALITY

Figures and Tables Continued: Page

Table of Contents Continued:

Comparison of CEAS and Williams-type Spring Wheat Yield Models for North Dakota and Minnesota

Summary of Conclusions and Recommendations

The CEAS yield model for spring wheat is more accurate, more precise, and more responsive to actual yield variations than is the Williams-type model by a small but consistent factor. This advantage holds for CRD, state, and regional yield estimates. The models appear to be equally objective, adequate, timely, inexpensive, and simple. Both incorporate scientific knowledge on a broad scale to about the same degree. Neither provides a useful current estimate of modeled yield reliability. The CEAS yield model appears to be the most appropriate model for use in the AgRISTARS Fiscal Year 81 Pilot Tests for spring wheat in North Dakota and Minnesota.

Applications Description

Testing and evaluation of candidate crop yield models for use with particular crops in particular geographical regions are major tasks within the Yield Model Development Project of the AgRISTARS Program. A YMD document (W. W. Wilson, T. L. Barnett, S. K. LeDuc, F. B. Warren, "Crop Yield Project, Document YMD - 1 - 1 - 2 (80.-2.1) establishes a common reference for describing yield model performance and criteria for evaluation.

Two yield models for spring wheat were evaluated and compared. The first, the CEAS Model, was developed by the Center for Environmental Assessment Services (CEAS), and NOAA center in Columbia, Missouri, (LeDuc, S.K.). The second, the Williams-type Model, was developed by the Yield

ORIGINAL PAGE IS
OF POOR QUALITY

Model Development Group at Columbia, Missouri based on an analytical model for Canadian cereal grains described by G. D. V. Williams (G. D. V. Williams, M. I. Joynt, P. A. McCormick, "Regression Analysis of Canadian Prairie Crop-District Cereal Yields, 1961-1972, in Relation to Weather, Soil, and Trend, "Can. J. Soil Sci. 55: Feb. 1975).

These two predictive models were evaluated according to the above mentioned criteria for potential applicability in the AgRISTARS Fiscal Year 81 Pilot Tests on spring wheat in North Dakota and Minnesota. Results of the individual model tests are described in the forthcoming YMD documents "Evaluation of the CEAS Trend and Monthly Weather Data Models for Spring Wheat Yields in North Dakota and Minnesota" and "Evaluation of Williams-Type Spring Wheat Model in North Dakota and Minnesota." The current document compares the results of performance tests on the two models and makes recommendations as to which model is best suited for current AgRISTARS Pilot Test needs.

Review of Models

CEAS MODEL

Basic inputs to the model were historical USDA yields and monthly mean temperature and total precipitation at the Crop Reporting District (CRD) level. A wide variety of possible weather-related variables, such cumulative precipitation from the previous September, monthly temperature and precipitation departures from normal and evapotranspiration (potential, actual, and "climatically appropriate") were formed from the basic inputs. Trends, accounting for general improvements in technology over the years, were defined.

ORIGINAL PAGE IS
OF POOR QUALITY

Linear functions of the year number are used as surrogates for technology in all models. The single trend term for all of the Minnesota models allows a linear increase in yield between 1955 and 1978. Contributions to yield from technology are considered for possible inclusion in the North Dakota models. One allows a linear increase in yield between 1955 and 1966, the next a linear increase between 1966 and 1973, and the last a linear increase from 1973 on. The first trend term, between 1955 and 1966, is included in all of the North Dakota models. The second term, between 1966 and 1973, is included only in the model for ND CRD 90. The third trend term is not included in any model. The contribution to yield from technology is considered nil for any time period not covered by an included trend term.

The general form of the CEAS yield model was:

$$\hat{Y}_i = a + b\ \text{TREND1}_i + b'\ \text{TREND2}_i + b''\ \text{TREND3}_i + \sum_{k=1}^{n} c_k\ W_{ik}$$

where:

$\hat{Y}_i$ = estimate of yield for i-th year

a = intercept (constant term)

b b'b" = linear trend coefficients

C_k = slope coefficient associated with the k-th weather term

W_{ik} = k-th weather term for the i-th year

In developing the models for each CRD (MN CRD's 10 and 40, ND CRD's 10 through 90) and state (MN and ND) stepwise multiple regressions were run to examine the possible variables and select the statistically most significant set of several trend and weather terms on the basis of years 1932-1978 for ND and 1936-1978 for MN. A certain amount of judgement was

ORIGINAL PAGE IS
OF POOR QUALITY

used to eliminate terms obviously in conflict with scientific knowledge (e.g., when a coefficient was strongly negative where it should be positive) or to include important terms even if they were not statistically significant. Model terms and ranges of coefficients over the ten test years are given in the CEAS spring wheat model evaluation document referenced above.

WILLIAMS-TYPE MODEL

In the models for Canadian wheat developed by G. D. V. Williams, barley and rye crop district weather and agronomic data were pooled to larger soil color regions. Soil texture and topographic information were incorporated along with trend and weather. A predictive yield model for barley in North Dakota (ND) and Minnesota, (MN) based on the concepts outlined by Williams et. al., was developed and tested by the AgRISTARS Yield Model Development Group. The model incorporated CRD-level weather (monthly mean temperature and total precipitation), soil texture and topography in a manner similar to that used by Williams. The CRD-level data were pooled to the following two more-or-less environmentally homogeneous regions:

(a) Red River Valley (MNRR)-consisting of ND CRD's 30 and 60 and MN CRD's 10 and 40;

(b) The remainder of North Dakota (NDREM)-consisting of ND CRD's 10, 20, 40, 50, 70, 80, and 90.

Separate models were developed for the two regions to provide predictions of CRD yields using individual CRD weather/soil data with coefficients from the pooled model. Models were also developed for the two states, ND and MN, based on state-aggregated weather/soil data.

Models were developed on the basis of data from 1932 through 1979. The terms were selected from stepwise regressions from which the most significant ten (or fewer) terms were retained for each region. A limit of 10 terms had been used by Williams et. al. and seemed to be a reasonable upper limit in applying this method. The basic weather/soil/trend inputs were monthly mean temperature; total monthly precipitation; percent of soils in the CRD in textural classes-coarse, medium and fine; percent of CRD area in the topographic classes-level to gently undulating; and year as surrogate for technological trend. These inputs were used to calculate the possible model variables.

Trend as defined for CEAS model
Tx = .75x(%find soil) + .65X (%medium soil) + .35X(%coarse soil);
Tx squared
Top = % of area level to gently undulating;
Top squared;
C = precipitation September-April;
C squared;
E5, E6, E7 - potential evapotranspiration calculated by the
Thornthwaite method (1948) for May, June, July;
D6, D7* = moisture deficits = E - precipitation for June, July;
D5, D6, D7 squared;
DO = seasonal deficit = D5 + D6 + D7 - C;
DO squared;
Tx X Do

*D5 was not used since D5, D6, D7, C, and Do are not all mutually independent.

Of these possible terms, the stepwise regression selected ten or fewer terms for each region. The terms judged to be statistically significant and the ranges of coefficients over the ten test years are presented in the Williams-type spring wheat evaluation report referenced above.

COMPARISON METHODOLOGY

Eight Model Characteristics to be Compared

The document referenced previously, Crop Yield Model Test and Evaluation Criteria, (Wilson, et al., 1980) states:

> "The model characteristics to be emphasized in the evaluation process are: yield indication reliability, objectivity, consistency with scientific knowledge, adequacy, timeliness, minimum cost, simplicity, and accurate current measures of modeled yield reliability."

The models will be compared using these characteristics. Each characteristic is discussed individually without regard to the other characteristics. The present discussion makes no presumption as to the relative importance of the characteristics.

Quantitative Model Comparisons Are Based on the Same Data

Direct quantitative comparison between models are made for two of the criteria, Yield Indication Reliability and Accurate Current Measures of Modeled Yield Reliability. The quantities involved are derived from the observed yields and standard errors of prediction obtained from independent bootstrap test for each of ten years (1970-1979). The same base period is used for all models in computing model-related values for a particular year.

The average production and yield over the ten year test period are listed in Table 1 for each geographic area, along with the percent production each crop reporting district (CRD) contributes it its state and the two state region and the percent production each state contributes to the region. The percentage of regional production for each CRD is shown graphically in Figure 1. In all the figures, darker shades indicate higher productivity.

Separate yield predictions are made for each CRD, state, and for the regions. Yield predictions and standard errors of prediction at the state level are also obtained by using a weighted average of that state's CRD model values, and yield values for the region are obtained using a weighted average of the values from the CRD models and from the state models. The weighting factor used is harvested acreage. Results obtained by aggregating from the CRD models are identified in tables as "CRD aggr." results obtained by aggregating from the state models are identified as "states aggr."

Models Are Ranked According to Performance

Models are ranked for each of the following indicators of yield reliability (order does not imply relative importance):

(1) the bias,

(2) the root mean square error (RMSE),

(3) the standard deviation (SD),

(4) the percent of years the absolute value of the relative difference exceeds ten percent,

(5) the largest absolute value of the relative difference,

(6) the next largest absolute value of the relative difference.

(7) the percent of years in which the direction of change from the previous year in the $\hat{Y}$'s agrees with the Y's.

(8) the percent of years in which the direction of change from the average of the previous three years in the $\hat{Y}$'s agrees with the Y's, and

(9) the Pearson correlation coefficient between the actual and predicted yields during the independent test years.

Models are also ranked according to the value of the Spearman correlation co-efficient which indicates the utility of the model's current measure of modeled yield reliability. For the indicatior (1) - (6), the model with the smallest numeric value exhibits the best performance in terms of yield reliability and is given a rank of 1. For the remaining quantities, the model with the largest value exhibits the most desirable performance. If models are tied for the same level of performance, they are all assigned the lowest rank for which they are tied. For example, if two models are tied for best performance, they are both assigned a rank of 1, the lower of ranks 1 and 2.

It should be remembered that the models are ranked only in relation to each other and not to an absolute standard. Therefore, saying that a particular model performs best or is superior to or more desirable than another model does not necessarily imply that the model is the best of all possible models. It is the best of only those with which it is currently being compared.

Models are Compared Using Statistical Tests Based on $D = \hat{Y} - Y$

It is desirable to run a statistical test comparing the reliability of competing models. A formal statistical test considers the variability of model performance over time and allows the user to specify an upper limit on the probability of incorrectly declaring one model better than another. This probability is known as α, the level of significance, or the Type I error. However, because the models are similar, a powerful statistical procedure is needed which is able to detect small, although important, differences in reliability. Also, the test should be able to function well with relatively small samples of data for each model, say ten years.

The test should also perform well when only two models are being compared. Often only two models of a particular type, for example, two monthly weather data models or two daily weather data models, are competitive and available for testing. When models of different types are to be compared, it is unlikely that all possible model comparisons will be made. It is more likely that the best models of each type will be compared.

It would appear that an F test could be useful in comparing the mean square errors of two models. However, if the mean square errors are based on ten years of test data and $\alpha = .05$, then one model's mean square error must be four times larger than another's before the models can be declared different. This is an unreasonable requirement since models which are in the evaluation process will almost always be more competitive than this.

A test may be constructed by considering that one model is considered more reliable than another model if its predicted yields, $\hat{Y}$'s, are closer to the actual yields, Y's. No difference in the reliability of two models for a particular year means that the absolute value of the difference between their predicted yields and the actual yield is the same. The absolute value of the difference is used because it does not matter whether one model overestimates and the other underestimates or whether they both over or underestimate. The reliability of a model for that year is related to the amount of the discrepancy, not its direction. We may define $|d_1| = |\hat{Y}_1 - Y|$, $|d_2| = |\hat{Y}_2 - Y|$, and $D = |d_1| - |d_2|$. Then the models are equally reliable in a year for which D equals zero. If D is not equal to zero, one model is more reliable than the other for that year. In formal

ORIGINAL PAGE IS
OF POOR QUALITY

terms, we want to test the null hypothesis that there is no difference in the reliability of the models over all years. To do so the values of D from the ten test years may be used to compute a test statistic and a decision made whether or not to reject the null hypothesis. Since the results for the models are paired each year, paired-sample statistical tests are used.

Two types of paired-sample statistical tests are used: a parametric test using the student "t" test statistic and a nonparametric test using the Wilcoxon signed rank test statistic. One reason for applying both tests is that they require different assumptions. The parametric t-test assumes the D values are normally distributed while the nonparametric test does not. The $|d|$ values may be considered to be approximately normally distributed. The $|d|$ values would then be folded normals rather than normally distributed. Although both models are folded at $|d| = 0$, their means may be different and the distribution of D has a possibility of not being normally distributed. The t-test is robust with respect to the normality assumption; however, this possible violation of the assumption is one reason for also running the nonparametric test.

The other reason for running both tests concerns the conditions under which the null hypothesis is rejected by each test. Using the parametric test, the basis for rejecting the null hypothesis is the average size of the D values as compared to their variability. The t-test statistic is the average of the sample standard error of the D's. The hypothesis will be rejected and the model with the smaller $|d|$ values declared more reliable if t is large (either positive or negative). However, it is possible that

one model could have a smaller $|d|$ value for each of the test years, in other words, be very consistent in outperforming the other model, and still the null hypothesis may not be rejected by the parametric test unless the average value of D is large enough. The parametric test implicitly requires that one model have more years with smaller $|d|$ values than the other model and explicitly requires that, on the average, the $|d|$ varies by a sufficient amount before that model may be declared more reliable.

The hypothesis of equal model performance will only be rejected by the nonparametric test if one model has more years with smaller $|d|$ values than the other model. The model with more smaller $|d|$ values is considered the more reliable model in terms of consistency of performance. However, to reject the null hypothesis and declare one model clearly better than another, consistency of performance is not a sufficient requirement (although it is necessary). Consider the situation in which one model is more consistent than the other but the largest D values occur when the less cinsistent model performs better. In the few years the less consistent model performs better, it performs much better. A dilemma exists since one model is more consistent than the other but the biggest differences between the models occur when the consistent model performs worse. The null hypothesis will be rejected only if one model is more consistent and the biggest differences between the models occur when the consistent model performs better.

MODEL COMPARISON

Quantitative comparison is made below of the CEAS and Williams-type models for spring wheat in North Dakota and Minnesota on the basis of bootstrap tests for test years 1970-1979. Reference is also made in the tables

and some figures to the "Strawman" Model. This is an objective linear one-line fit to the years previous to each test year, and thus represents a minimal "model". The strawman model contains no explicit weather-related information.

The actual SRS yields are plotted vs. year from the 1930's through 1979 for MN in Figure 2A and for ND in Figure 2B. The results of the ten-year bootstrap tests are plotted for MN in Figure 3A and for ND in 3B. An appendix presents the results of the ten-year bootstrap tests.

<u>Indicators of Yield Reliability Based on d = Y - Y Show the CEAS Model Slightly More Accurate With Respect to Root Mean Square Error, Standard Deviation, and Bias</u>.

Results of comparative tests are shown in Tables 2,3, and 4 and Figure 2.

<u>RMSE</u> The CEAS model had smaller RMSE over the ten test years 1970-1979 at the CRD level in five of eleven CRD's, while the Williams-type model has smaller RMSE in six CRD's (no ties). RMSE values for the CEAS model ranged from 1.17 to 4.18 Q/Ha at CRD level and from 1.13 to 2.09 Q/Ha at the state and regional levels. RMSE values for the Williams-type model ranged from 1.49 to 3.76 Q/Ha at CRD level and from 1.40 to 2.76 Q/Ha at state and regional levels. Average RMSE at CRD level was 2.01 Q/Ha for the CEAS model and 2.10 Q/Ha for the Williams-Type model.

<u>Standard Deviation</u> The standard deviation measures precision because the biases are all small, the standard deviations show the same pattern of behavior as RMSE values.

<u>Bias</u> Biases for both models are small. At CRD level the biases range from -0.78 to 1.68 Q/Ha for the CEAS model and from -2.42 to 1.90 Q/Ha for the Williams-type model. Overall the average of the absolute value for bias at CRD level is slightly smaller for the CEAS model (0.25 Q/Ha) than for the Williams-type model (0.54 Q/Ha).

ORIGINAL PAGE IS
OF POOR QUALITY

Indicators of Yield Reliability Based on rd = (d/y) * 100 Show the CEAS Model Slightly More Accurate in Extreme Years.

The model test results and comparative ranks for indicators of yield reliability based on relative difference, rd, are given in Tables 5, 6, and 7 and Figures 5, 6, and 7. These indicators are valuable for demonstrating the worst performance of a model. The best-performing model will have the smaller values for the percent of years the absolute value of relative difference exceeds ten percent, and for the largest and next largest absolute value of the relative difference.

The percent of years in which the absolute value of rd exceeds ten percent at CRD level was smaller or tied in eight cases for the CEAS model and in six cases for the Williams-type model. At state and regional level the CEAS model was better or tied in all cases; the Williams-type model was tied in three cases.

The largest absolute relative difference was smaller or tied at CRD level in eight cases for the CEAS model and in four cases for the Williams-type model. The CEAS model was better in al cases at state and regional levels.

The next largest absolute relative difference was smaller or tied at CRD level in five cases for the CEAS model and in six cases for the Williams-type model. The CEAS model was better or tied in four of six cases at state and regional levels, while the Williams-type model was better or tied in three of six cases.

The next largest absolute relative difference was smaller or tied at CRD level in six cases for the CEAS model and in five cases for the Williams-type model. The CEAS model was better in five of six cases at state and regional levels, while the Williams-type model was better in one case.

Indicators of Yield Reliability Based on $\hat{Y}$ and Y Show the CEAS Model With Better Response.

Plots of the predicted and actual yields over the ten test years for each state are displayed in Figures 2 and 3. The test results and comparative ranks for the indicators of yield reliability based on $\hat{Y}$ and Y are given in Tables 8, 9, and 10, and Figures 8, 9, and 10. These indicators demonstrate the degree of correspondence between predicted and actual yields. The best performing model will have the largest value for the percent of years in which the direction of change of $\hat{Y}$'s from the previous year and from the average of the three previous years agrees with that for Y's, and will have the largest value of the correlation coefficient between actual and predicted yields.

The percent of years in which the direction of change from the previous year is correct is larger or tied at CRD level in seven cases for the CEAS model and in six cases for the Williams-type model. At state and regional level the CEAS model is better or tied in two cases; the Williams-type model is better or tied in four cases.

The percent of years in which the direction of change from the average of the previous three years is correct is larger or tied at CRD level in eight cases for the CEAS model and in nine cases for the Williams-type model. At state and regional level the CEAS model is better or tied in two cases; the Williams-type model is better or tied in all six cases.

The Pearson correlation coefficient is larger at CRD level in six cases for the CEAS model and in five cases for the Williams-type model. At state and regional level the CEAS model is better in four cases, while the Williams-type model is better in two cases.

<u>Statistical Tests Based on $d = \hat{Y} - Y$</u>
<u>Show the CEAS Model Slightly Better.</u>

The results of the parametric and non-parametric paired - sample statistical tests are shown in Tables 11, 12, and 13 and Figures 11, 12, 13, and 14.

In those cases where significant differences exist, the CEAS model has smaller average $|d|$ than the Williams-type model one case for the parametric t-test and has larger percent smaller $|d|$ in one case for the non-parametric rank test. Overall, considering both significant and non-significant cases, there is no discernable difference.

<u>Both Models Provide a Poor</u>
<u>Current Measure of Modeled</u>
<u>Yield Reliability</u>

The Spearman correlation coefficient between the estimate of the standard error of a predicted yield from the base period model, $s\hat{y}$, and the avsolute value of the difference between the predicted and actual yield, $|d|$, indicates whether the model provides a useful current measure of modelled yield reliability. An r value close to +1 is desireable since it indicates that a smaller standard error of prediction (and therefore a narrower confidence interval about the predicted value) is associated with smaller discrepancies between predicted and actual yields. If this were the case one would have confidence in $s\hat{y}$ as (at least) a relative indicator of the accuracy of $\hat{Y}$.

ORIGINAL PAGE IS
OF POOR QUALITY

The results of the tests are given in Table 14. The results for both are so poor and so variable that one can have little confidence in $s\hat{y}$ as an indicator of the reliability of predictions $\hat{Y}$.

The Two Models Are About Equally Objective

Both models involve some subjectivity in specification of trend, choice of trend breakpoints, and stepwise selection of the "most significant" terms. Both are quite objective in application once these choices have been made.

Both Models Consider Known Scientific Relationships on a Broad Scale But Not in Detail

Stepwise selection of the most significant terms does not ensure physical or biological significance for either model. Although the process gives terms which represent general dependencies of yield on temperature and precipitation throughout the growing season, the wise variation from one region to another in terms which enter as "significant" does not give a great deal of confidence in their reality. In general, the set of significant terms for regression modelsof these sorts seem to fall somewhere between the poles of "physical reality" and "random fluctuation".

The policy of handling technology and cropping practice trends by piecewise linear and/or quadratic functions of year glosses over the known relationships to variety improvements, fertilizer usage, etc., but is currently the most practical way of handling a very complex problem. Rationale for choosing breakpoints appears to be practical rather than scientific. There is no known way to tell when a trend breakpoint has occurred until several years later. Because the trend breakpoints in both models were determined from examination of all years through 1978-1979,

there is a certain amount of pre-knowledge in the tests that one would not actually have in a real-life application. Neither model attempts to explicitly account for pests, disease, or other episodic events.

The use of textural and topographical information in the Williams-type model does not appear to give this model any advantages in practice since these terms do not even enter some of the models where one would expect them from an agronomic viewpoint. It is also not obvious if the CEAS models have any advantage in obtaining trends for each individual CRD as compared to the Williams-type model which obtained trend for a multi-CRD region.

Both Models Are Adequate Only for the Regions in Which They Were Developed

Neither model can be reliably extended outside the regions for which they were developed. Either can readily be built for any region for which a sufficient historical record of weather and yield exists. To some extent the Williams-type model allows substitution of geographical record for historical record and could, therefore, be at an advantage in certain foreign regions of limited historical record.

Both Models Are equally Timely

New models can be built as soon as reliable yield and weather figures for the past year are available. Early season yield predictions can be made shortly after the end of each month. In most CRD's a "final" yield prediction would be obtained as soon as weather data for July was obtained. This could be 1 to 5 weeks before harvest.

ORIGINAL PAGE IS
OF POOR QUALITY

Both Models Are Equally
Inexpensive to Develop and Run

Data to develop and run both models are readily available at low cost. The multiple regression programs needed to develop and run the models are available on most computer systems.

Both Models Are Equally Simple

For both models, development and application are straight-forward. The only points where judgement is required are in selection of significant terms and specification of trend.

CONCLUSIONS

By a small but consistent factor the CEAS model is preferable to the Williams-type model for predicting yields of spring wheat at CRD and state levels in North Dakota and Minnesota. The CEAS model is more accurate, more precise, and more responsive to changes in observed yields. Both models are local models, but can be readily redeveloped for other regions for which historical records of 20-30 years of yield and monthly weather data exist. Neither model incorporates scientific knowledge very deeply, and both are susceptible to large errors in years of unusual weather. However, both models seem to generally do a good job of relating weather to yield on average. Neither model provides a useful current estimate of modeled yield reliability.

The main practical difference between the two models appears to be the pooling of CRD level data over multi-CRD regions. The fact that the pooled model for spring wheat did nearly as well as the models at individual CRD levels indicates that the pooled approach is a feasible one. This could be useful in some foreign regions where historical record lengths are limited.

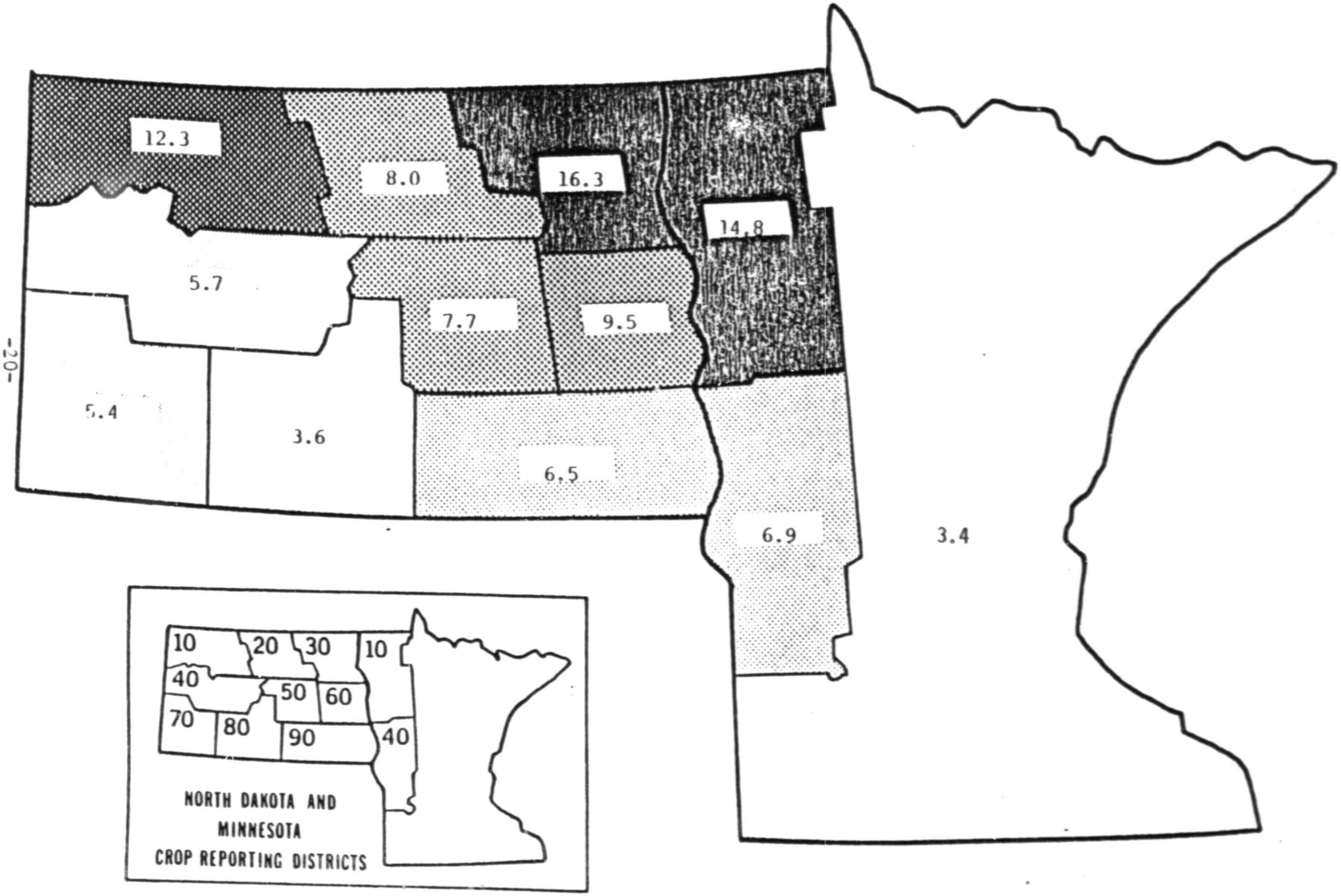
ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 1
AVERAGE PRODUCTION AND YIELD
FOR TEST YEARS 1970-77

SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

STATE	CRD	PRODUCTION (1.000) QUINTALS	BUSHELS	PERCENT OF STATE	REGION	YIELD QNTL/HA	BU/ACRE
N.DAKOTA	10	10.803	39.693	16.5	12.3	17.8	26.5
	20	6.985	25.664	10.6	8.0	17.1	25.5
	30	14.255	52.378	21.7	16.3	20.7	30.8
	40	4.965	18.242	7.6	5.7	16.7	24.8
	50	6.769	24.873	10.3	7.7	16.7	24.8
	60	8.280	30.422	12.6	9.5	20.3	30.3
	70	4.755	17.474	7.2	5.4	16.4	24.3
	80	3.123	11.473	4.8	3.6	13.1	19.5
	90	5.676	20.655	8.7	6.5	16.1	23.9
STATE		65.611	241.075		74.9	17.7	26.4
MINNESOTA	10	12.984	47.707	59.0	14.8	23.7	35.2
	20	131	480	0.6	0.1	19.4	29.8
	30	4	14	0.0	0.0	17.9	26.6
	40	6.025	22.136	27.4	6.9	20.6	30.6
	50	1.231	4.523	5.6	1.4	22.7	33.7
	60	43	158	0.2	0.0	20.0	29.7
	70	660	2.424	3.0	0.8	21.9	32.6
	80	664	2.441	3.0	0.8	24.2	35.9
	90	255	936	1.2	0.3	22.0	32.7
STATE		21.996	80.820		25.1	22.8	33.9
REGION		87.607	321.894			18.8	27.9

Figure 1. Percent of regional Spring Wheat Production contributed by individual CRDs (1970-79 average). Darker shades indicate higher production.



ORIGINAL PAGE IS
OF POOR QUALITY

Figure 2A

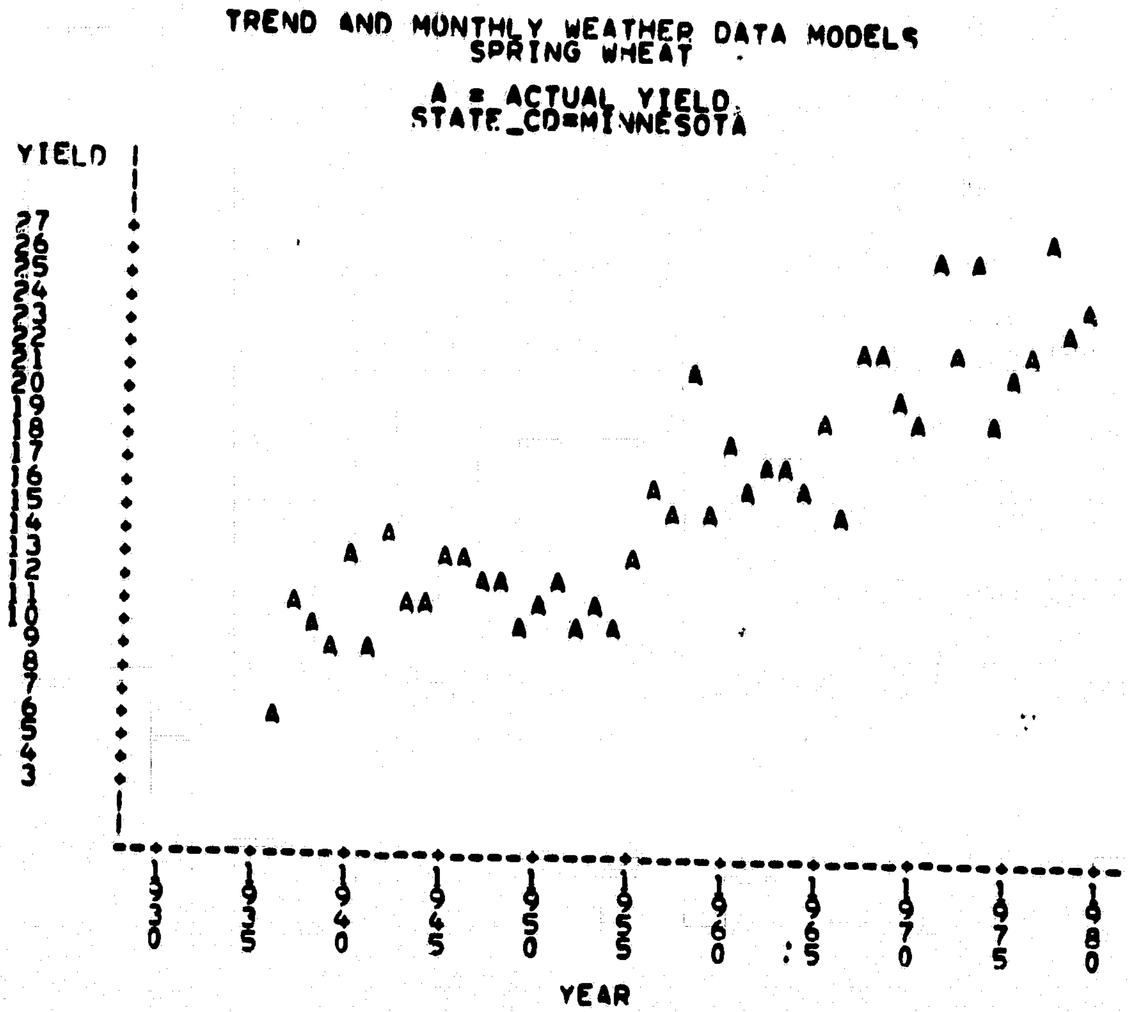
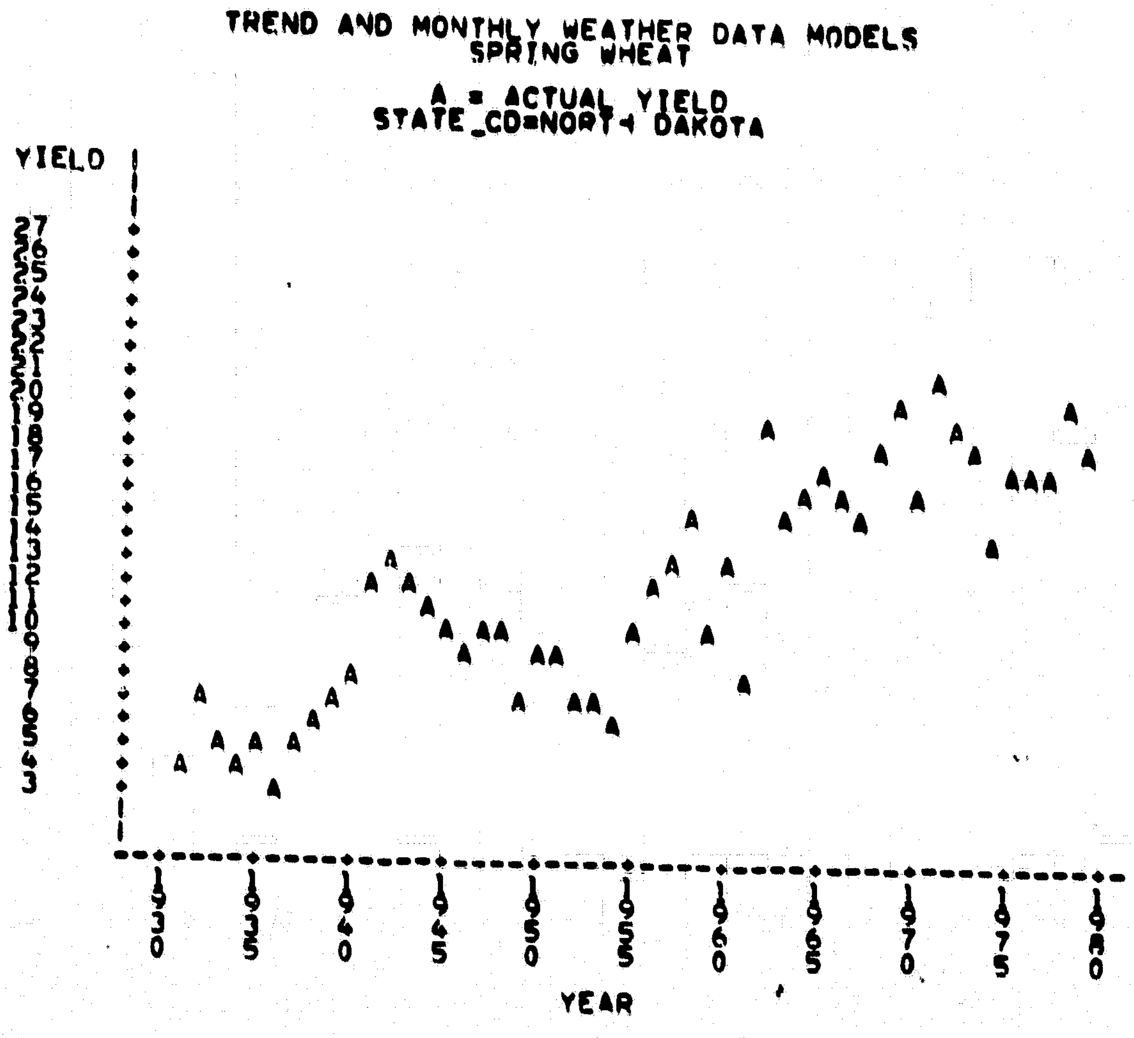
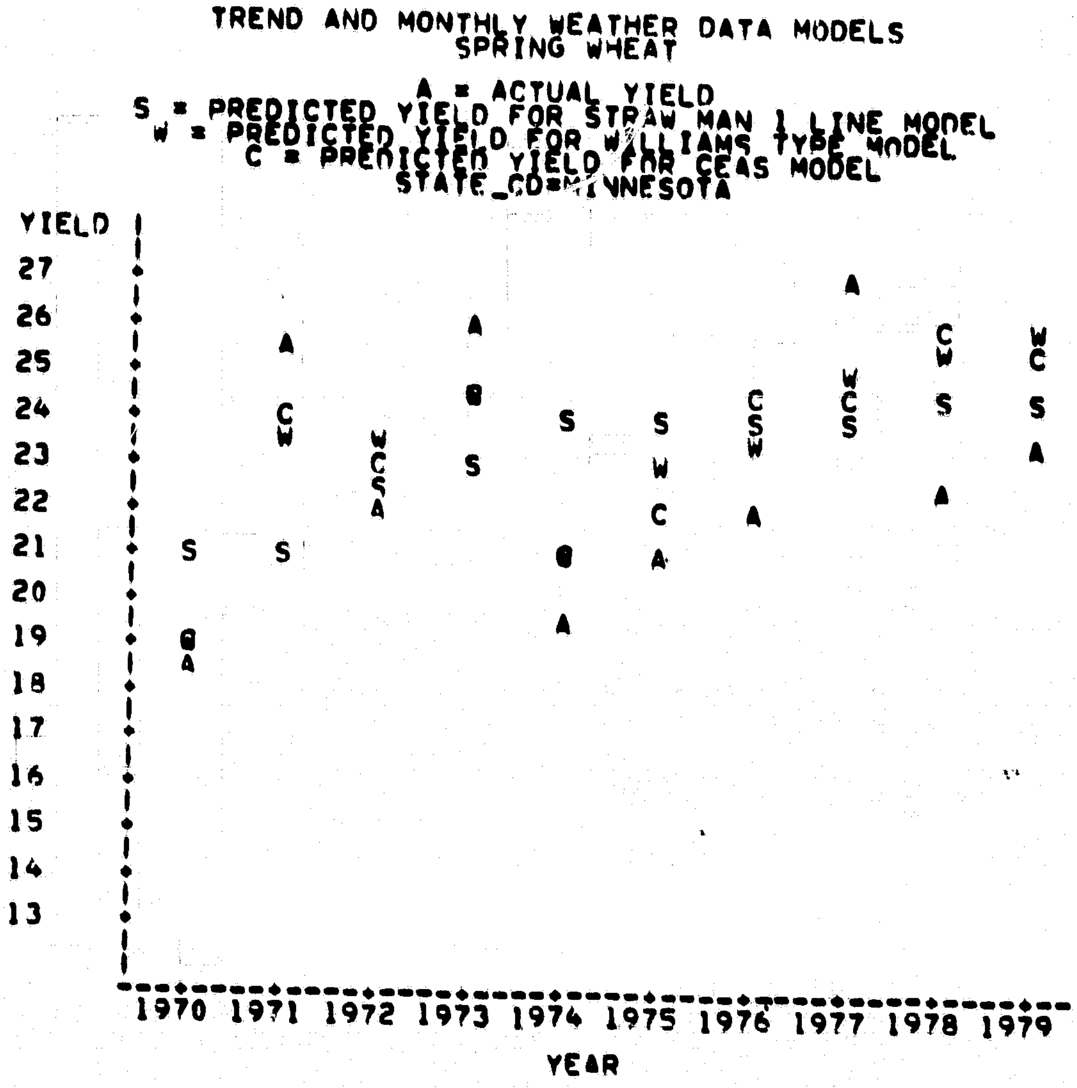


Figure 7B


TREND AND MONTHLY WEATHER DATA MODELS
SPRING WHEAT
A = ACTUAL YIELD
STATE_CD=NORTH DAKOTA
YIELD
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
YEAR

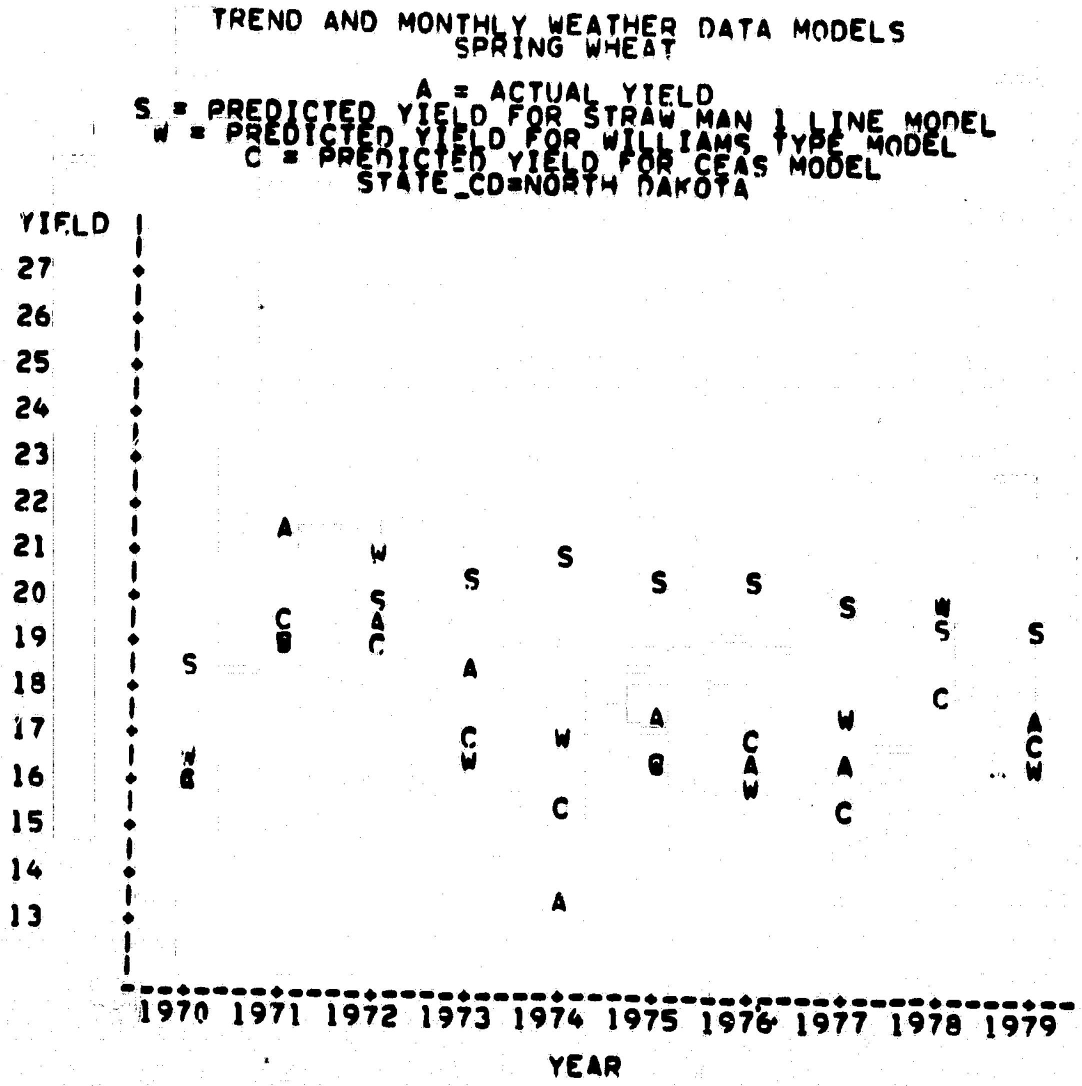
ORIGINAL PAGE IS
OF POOR QUALITY

Figure 3A



ORIGINAL PAGE IS
OF POOR QUALITY

Figure 3B



ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 2
MODEL COMPARISON BASED ON THE
ROOT MEAN SQUARE ERROR (QUINTALS/HECTARE)
DERIVED FROM INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

STATE	CRD	STRAWMAN RMSE	STRAWMAN RANK	WILLIAMS RMSE	WILLIAMS RANK	CEAS RMSE	CEAS RANK
N.DAKOTA	10	3.55	(3)	1.64	(1)	2.07	(2)
	20	3.86	(3)	2.00	(2)	1.46	(1)
	30	3.72	(3)	1.91	(2)	1.62	(1)
	40	3.43	(3)	1.49	(2)	1.17	(1)
	50	4.18	(3)	2.43	(1)	2.48	(2)
	60	3.57	(3)	1.74	(2)	1.65	(1)
	70	3.06	(3)	1.71	(1)	1.84	(2)
	80	3.63	(3)	2.40	(1)	2.83	(2)
	90	3.60	(3)	2.03	(1)	2.52	(2)
STATE MODEL		3.34	(3)	1.59	(2)	1.26	(1)
CRDS AGGR.		3.35	(3)	1.40	(2)	1.24	(1)
MINNESOTA	10	2.99	(3)	2.92	(2)	1.26	(1)
	40	4.86	(3)	3.76	(1)	4.18	(2)
STATE MODEL		2.90	(3)	1.90	(2)	1.86	(1)
CRDS AGGR.		2.96	(3)	2.76	(2)	2.09	(1)
REGION							
CRDS AGGR.		3.09	(3)	1.47	(2)	1.22	(1)
STATES AGGR.		3.01	(3)	1.44	(2)	1.13	(1)

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 3
MODEL COMPARISON BASED ON THE
STANDARD DEVIATION (QUINTALS/HECTARE)
DERIVED FROM INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

STATE	CRD	STRAWMAN SD	STRAWMAN RANK	WILLIAMS SD	WILLIAMS RANK	CEAS SD	CEAS RANK
N.DAKOTA	10	2.88	(3)	1.47	(1)	2.06	(2)
	20	2.91	(3)	1.83	(2)	1.37	(1)
	30	2.91	(3)	1.87	(2)	1.61	(1)
	40	2.92	(3)	1.45	(2)	1.13	(1)
	50	3.32	(3)	2.25	(1)	2.35	(2)
	60	2.91	(3)	1.48	(1)	1.56	(2)
	70	2.47	(3)	1.71	(1)	1.73	(2)
	80	2.95	(3)	1.47	(1)	2.62	(2)
	90	3.11	(3)	2.03	(1)	2.34	(2)
STATE MODEL		2.55	(3)	1.59	(2)	1.12	(1)
CRDS AGGR.		2.56	(3)	1.35	(2)	1.24	(1)
MINNESOTA	10	2.98	(3)	1.63	(2)	1.02	(1)
	40	4.72	(3)	3.44	(1)	3.83	(2)
STATE MODEL		2.86	(3)	1.76	(1)	1.76	(2)
CRDS AGGR.		2.91	(3)	1.76	(1)	1.81	(2)
REGION							
CRDS AGGR.		2.46	(3)	1.28	(2)	1.20	(1)
STATES AGGR.		2.41	(3)	1.44	(2)	1.08	(1)

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 4
MODEL COMPARISON BASED ON THE
BIAS (QUINTALS/HECTARE)
DERIVED FROM INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

STATE	CRD	STRAWMAN BIAS	STRAWMAN RANK	WILLIAMS BIAS	WILLIAMS RANK	CEAS BIAS	CEAS RANK
N.DAKOTA	10	2.08	(3)	-0.72	(2)	0.21	(1)
	20	2.54	(3)	-0.82	(2)	0.51	(1)
	30	2.31	(3)	-0.41	(2)	-0.11	(1)
	40	1.80	(3)	-0.32	(2)	-0.28	(1)
	50	2.54	(3)	-0.91	(2)	-0.78	(1)
	60	2.08	(3)	-0.91	(2)	-0.53	(1)
	70	1.80	(3)	0.15	(1)	-0.64	(2)
	80	2.12	(3)	1.90	(2)	1.06	(1)
	90	1.81	(3)	0.01	(1)	0.92	(2)
STATE MODEL		2.16	(3)	-0.09	(1)	-0.58	(2)
CRDS AGGR.		2.17	(3)	-0.35	(2)	0.04	(1)
MINNESOTA	10	0.24	(1)	-2.42	(3)	0.73	(2)
	40	1.16	(1)	-1.53	(2)	1.68	(3)
STATE MODEL		0.47	(1)	0.73	(3)	0.59	(2)
CRDS AGGR.		0.53	(1)	-2.12	(3)	1.06	(2)
REGION							
CRDS AGGR.		1.86	(3)	-0.71	(2)	0.23	(1)
STATES AGGR.		1.80	(3)	0.09	(1)	-0.35	(2)

Figure 4 Letter indicates the model with smallest root mean square error for spring wheat yields based on test years 1970-1979 (C = CEAS, W = Williams-type, S = Strawman).

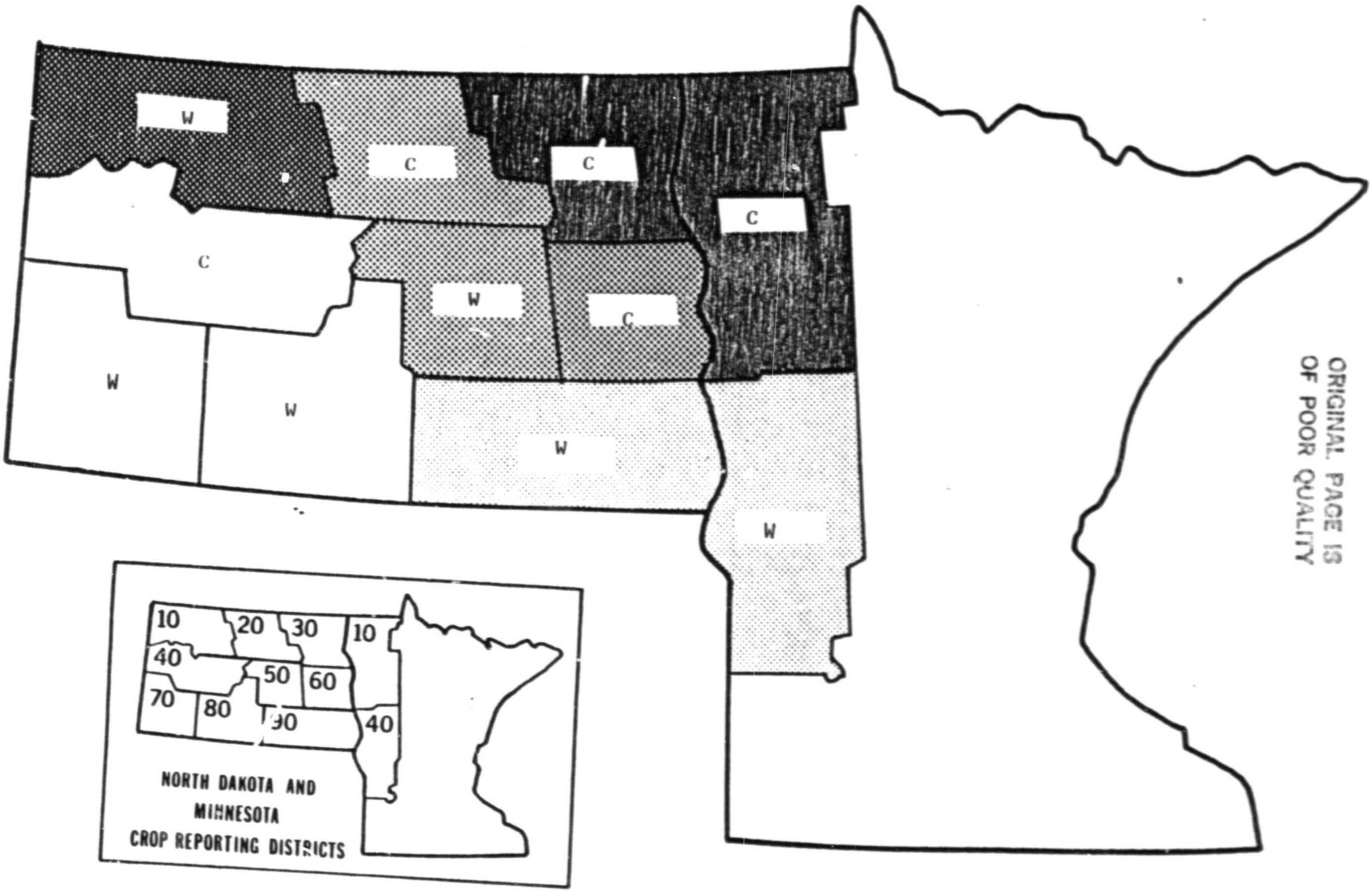


TABLE 5
MODEL COMPARISON BASED ON THE
PERCENT OF YEARS |RELATIVE DIFFERENCE| > 10%
DERIVED FROM INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

STATE	CRD	STRAWMAN %	STRAWMAN RANK	WILLIAMS %	WILLIAMS RANK	CEAS %	CEAS RANK
N.DAKOTA	10	70	(3)	30	(1)	30	(1)
	20	70	(3)	40	(2)	30	(1)
	30	70	(3)	30	(2)	20	(1)
	40	50	(3)	30	(1)	30	(1)
	50	80	(3)	40	(1)	50	(2)
	60	60	(3)	30	(2)	20	(1)
	70	70	(3)	50	(2)	20	(1)
	80	70	(1)	70	(1)	70	(1)
	90	60	(3)	40	(1)	50	(2)
STATE MODEL		80	(3)	30	(2)	10	(1)
CRDS AGGR.		80	(3)	20	(1)	20	(1)
MINNESOTA	10	30	(2)	50	(3)	10	(1)
	40	80	(2)	50	(1)	80	(2)
STATE MODEL		60	(3)	20	(1)	20	(1)
CRDS AGGR.		60	(3)	40	(2)	30	(1)
REGION							
CRDS AGGR.		60	(3)	30	(2)	20	(1)
STATES AGGR.		50	(3)	30	(2)	10	(1)

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 6
MODEL COMPARISON BASED ON THE LARGEST (RELATIVE DIFFERENCE) DERIVED FROM INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

		MODEL					
		STRAWMAN		WILLIAMS		CEAS	
STATE	CRD	RD	RANK	RD	RANK	RD	RANK
N.DAKOTA	10	43.2	(3)	-17.9	(1)	23.1	(2)
	20	63.6	(3)	23.3	(2)	20.9	(1)
	30	58.2	(3)	21.6	(2)	17.6	(1)
	40	69.8	(3)	24.1	(2)	-11.0	(1)
	50	64.2	(3)	32.5	(2)	-24.3	(1)
	60	50.3	(3)	-13.7	(1)	15.9	(2)
	70	35.5	(3)	-15.7	(1)	-20.4	(2)
	80	86.2	(3)	47.1	(1)	69.0	(2)
	90	56.3	(3)	21.7	(1)	37.2	(2)
STATE MODEL		54.0	(3)	23.4	(2)	14.6	(1)
CRDS AGGR.		54.0	(3)	17.5	(1)	17.5	(1)
MINNESOTA	10	33.3	(3)	-16.7	(2)	11.3	(1)
	40	53.0	(3)	-29.7	(1)	41.6	(2)
STATE MODEL		24.1	(3)	12.8	(1)	13.7	(2)
CRDS AGGR.		27.5	(3)	-18.3	(2)	12.7	(1)
REGION							
CRDS AGGR.		47.6	(3)	-13.2	(1)	16.3	(2)
STATES AGGR.		46.3	(3)	19.5	(2)	12.8	(1)

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 7
MODEL COMPARISON BASED ON THE
NEXT LARGEST (RELATIVE DIFFERENCE)
DERIVED FROM INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

		MODEL					
		STRAWMAN		WILLIAMS		CEAS	
STATE	CRD	RD	RANK	RD	RANK	RD	RANK
N.DAKOTA	10	41.4	(3)	-11.0	(1)	-16.9	(2)
	20	34.5	(3)	-16.2	(2)	13.4	(1)
	30	17.6	(3)	-15.0	(2)	-12.6	(1)
	40	24.3	(3)	-11.3	(2)	-10.8	(1)
	50	37.3	(3)	-24.4	(2)	20.8	(1)
	60	21.7	(3)	-13.5	(2)	-10.2	(1)
	70	31.9	(3)	12.8	(1)	-16.1	(2)
	80	40.5	(3)	28.2	(1)	29.7	(2)
	90	46.5	(3)	-19.5	(1)	25.4	(2)
STATE MODEL		22.9	(3)	-11.4	(2)	-10.0	(1)
CRDS AGGR.		22.9	(3)	-13.1	(2)	10.8	(1)
MINNESOTA	10	-19.3	(3)	-15.0	(2)	7.6	(1)
	40	31.2	(3)	-24.3	(1)	29.5	(2)
STATE MODEL		-17.2	(3)	10.0	(1)	11.9	(2)
CRDS AGGR.		-18.1	(3)	-13.0	(2)	12.4	(1)
REGION							
CRDS AGGR.		20.6	(3)	12.2	(2)	10.6	(1)
STATES AGGR.		19.0	(3)	-10.5	(2)	-8.6	(1)

Figure 5 Letter indicates the mode, for spring wheat with the smallest percent of test years (1970-1979) having absolute values of the relative difference greater than ten percent (C = CEAS, W = Williams - type, S = Strawman).

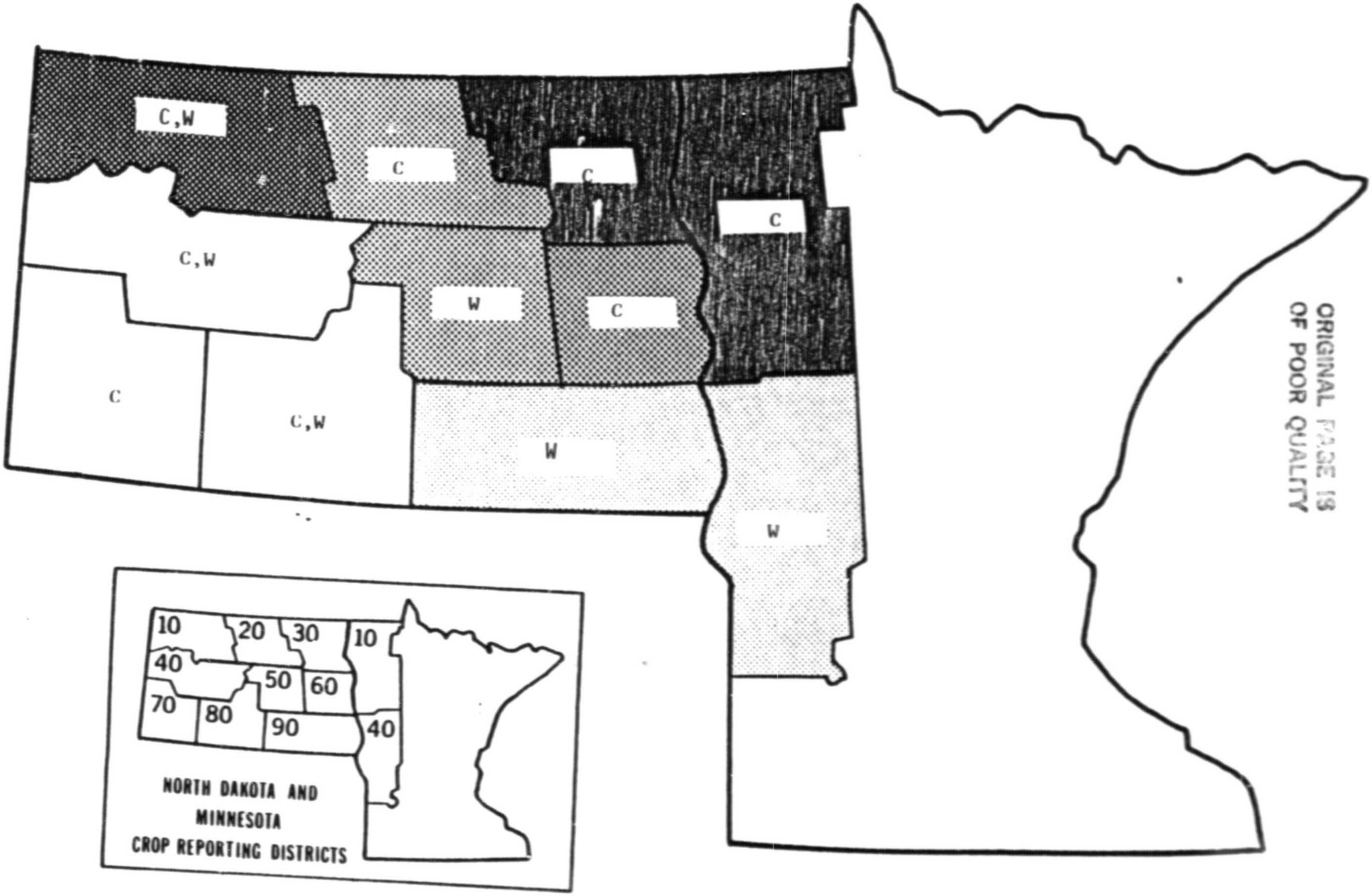


Figure 6. Letter indicates the model for absolute spring wheat with the smallest value of the largest obsolute relative difference during the test years 1970=1979 (C = CEAS, W = Williams-type, S = Strawman).

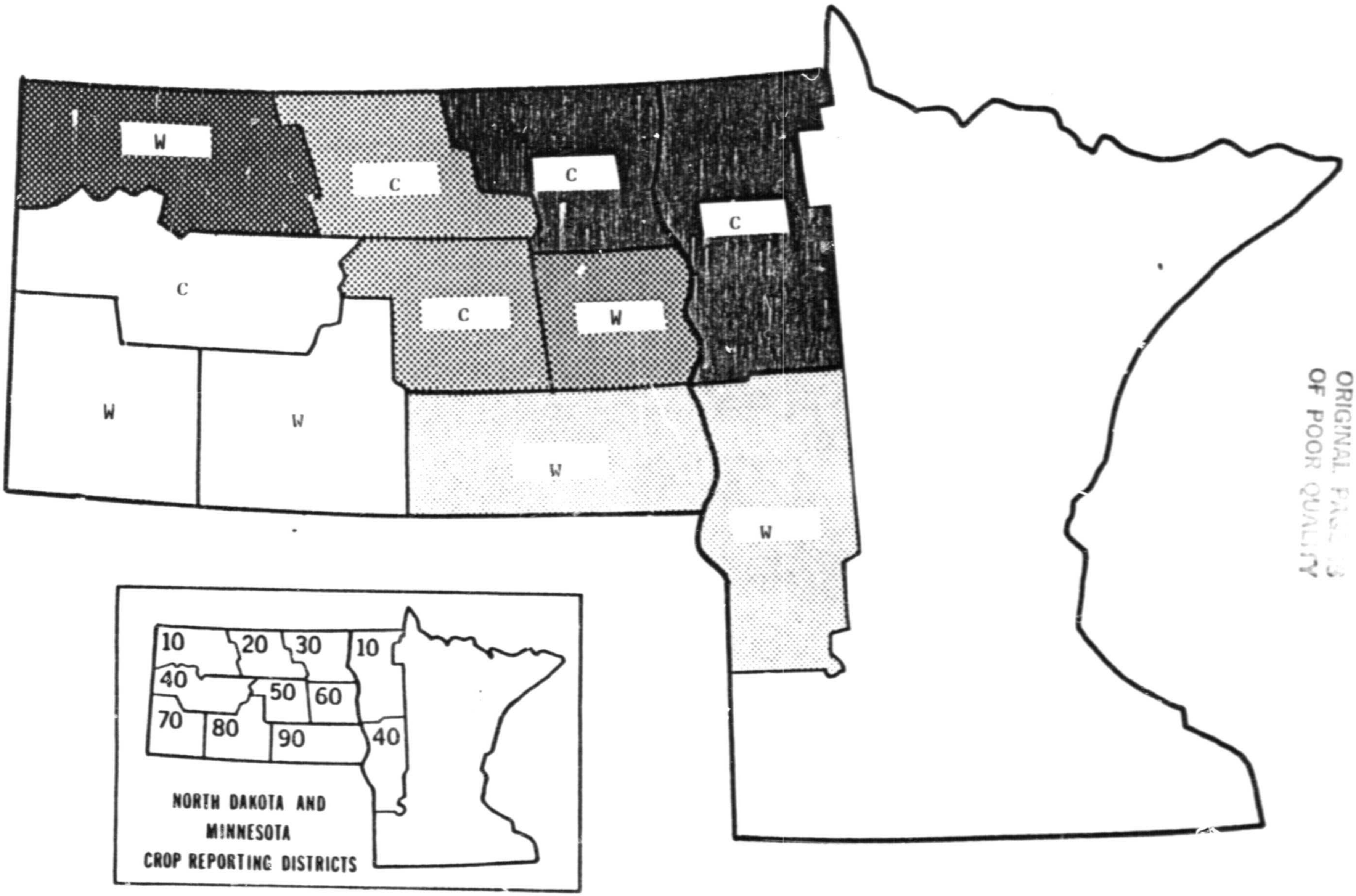
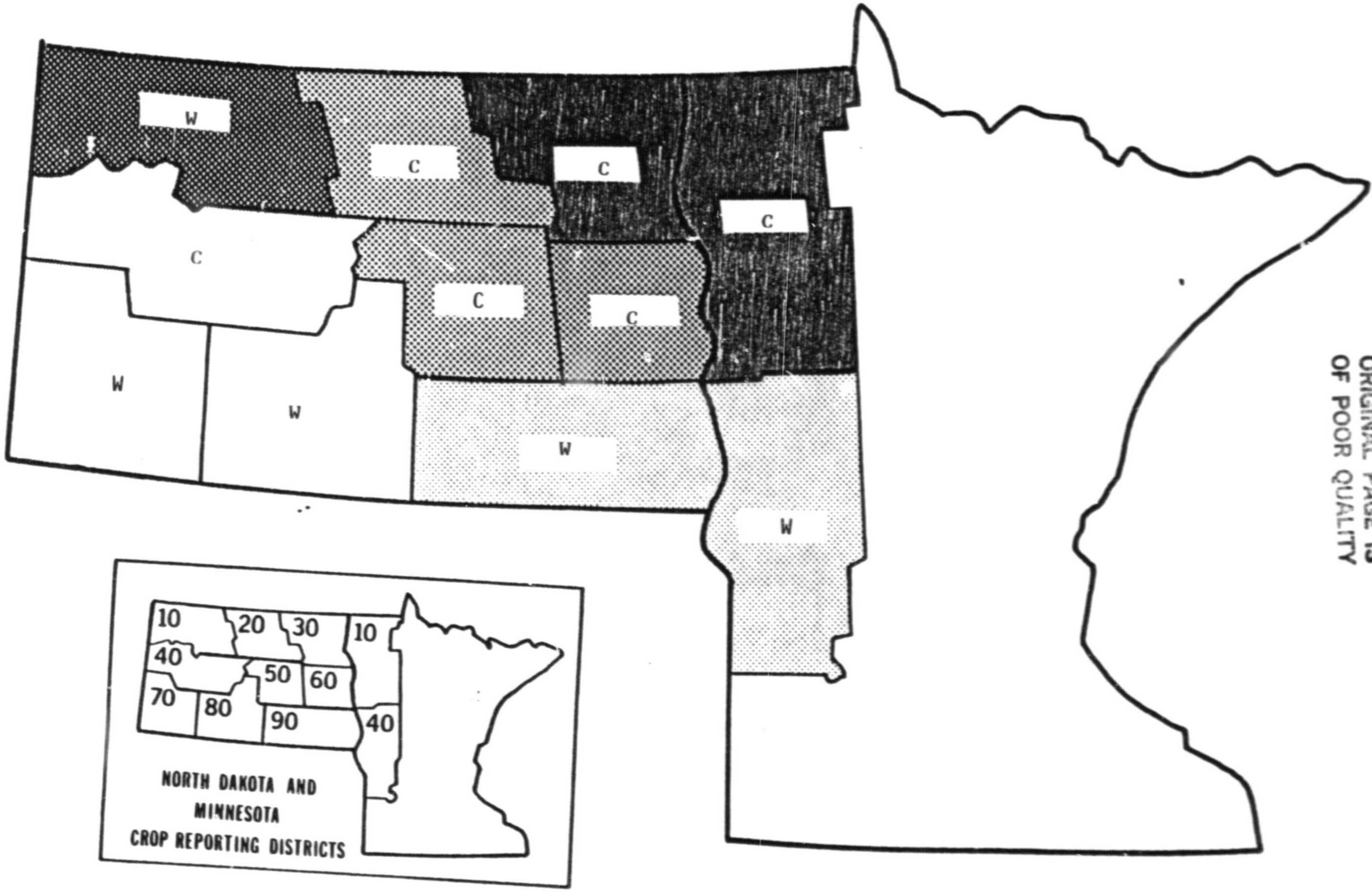


Figure 7. Letter indicates the model for spring wheat with the smallest value of the next largest absolute relative difference during the test years 1970-1979 (C = CEAS, W = Williams-type, S = Strawman).



ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 8
MODEL COMPARISON BASED ON THE
PERCENT OF YEARS THE DIRECTION OF CHANGE
FROM THE PREVIOUS YEAR IS CORRECT
DURING INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

		MODEL					
		STRAWMAN		WILLIAMS		CEAS	
STATE	CRD	%	RANK	%	RANK	%	RANK
N.DAKOTA	10	33	(3)	78	(1)	78	(1)
	20	33	(3)	56	(2)	78	(1)
	30	11	(3)	67	(2)	78	(1)
	40	33	(3)	89	(1)	78	(2)
	50	44	(3)	56	(2)	89	(1)
	60	22	(3)	89	(1)	89	(1)
	70	44	(3)	67	(2)	78	(1)
	80	22	(3)	78	(1)	67	(2)
	90	33	(3)	67	(1)	56	(2)
STATE MODEL		22	(3)	67	(2)	78	(1)
CRDS AGGR.		22	(3)	89	(1)	78	(2)
MINNESOTA	10	22	(3)	67	(2)	89	(1)
	40	22	(3)	78	(1)	67	(2)
STATE MODEL		22	(3)	78	(1)	67	(2)
CRDS AGGR.		33	(3)	44	(2)	56	(1)
REGION							
CRDS AGGR.		22	(3)	78	(1)	56	(2)
STATES AGGR.		11	(3)	78	(1)	67	(2)

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 9
MODEL COMPARISON BASED ON THE
PERCENT OF YEARS THE DIRECTION OF CHANGE
FROM A THREE YEAR BASE PERIOD IS CORRECT
DURING INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

		MODEL					
		STRAWMAN		WILLIAMS		CEAS	
STATE	CRD	%	RANK	%	RANK	%	RANK
N.DAKOTA	10	14	(3)	71	(1)	71	(1)
	20	43	(3)	86	(2)	100	(1)
	30	0	(3)	71	(1)	71	(1)
	40	29	(3)	71	(1)	71	(1)
	50	14	(3)	71	(1)	57	(2)
	60	0	(3)	57	(1)	57	(1)
	70	57	(1)	57	(1)	57	(1)
	80	43	(3)	86	(1)	86	(1)
	90	14	(3)	86	(2)	100	(1)
STATE MODEL		14	(3)	71	(1)	57	(2)
CRDS AGGR.		14	(3)	71	(1)	57	(2)
MINNESOTA	10	57	(3)	100	(1)	86	(2)
	40	14	(3)	86	(1)	57	(2)
STATE MODEL		14	(3)	57	(1)	57	(1)
CRDS AGGR.		43	(3)	86	(1)	86	(1)
REGION							
CRDS AGGR.		43	(3)	86	(1)	57	(2)
STATES AGGR.		29	(3)	86	(1)	71	(2)

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 10
MODEL COMPARISON BASED ON THE
CORRELATION BETWEEN ACTUAL AND PREDICTED YIELDS
DURING INDEPENDENT TEST YEARS

TREND AND MONTHLY WEATHER DATA MODELS
SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

STATE	CRD	STRAWMAN R	STRAWMAN RANK	WILLIAMS R	WILLIAMS RANK	CEAS R	CEAS RANK
N.DAKOTA	10	-0.39	(3)	0.79	(1)	0.70	(2)
	20	-0.40	(3)	0.67	(2)	0.92	(1)
	30	-0.62	(3)	0.62	(2)	0.74	(1)
	40	-0.30	(3)	0.83	(2)	0.90	(1)
	50	-0.45	(3)	0.60	(2)	0.61	(1)
	60	-0.56	(3)	0.82	(1)	0.78	(2)
	70	-0.18	(3)	0.66	(2)	0.67	(1)
	80	-0.31	(3)	0.84	(1)	0.50	(2)
	90	-0.51	(3)	0.64	(1)	0.54	(2)
STATE MODEL		-0.43	(3)	0.67	(2)	0.89	(1)
CRDS AGGR.		-0.43	(3)	0.77	(2)	0.81	(1)
MINNESOTA	10	0.10	(3)	0.90	(2)	0.94	(1)
	40	-0.32	(3)	0.77	(1)	0.41	(2)
STATE MODEL		0.04	(3)	0.75	(1)	0.74	(2)
CRDS AGGR.		-0.01	(3)	0.83	(1)	0.74	(2)
REGION							
CRDS AGGR.		-0.34	(3)	0.79	(2)	0.81	(1)
STATES AGGR.		-0.30	(3)	0.70	(2)	0.88	(1)

Figure 8. Letter indicates the model for spring wheat with the largest percentage of test years (1970–1979) having agreement in direction of change from the previous year between predicted and actual yields (C = CEAS, W = Williams-type, S = Strawman).

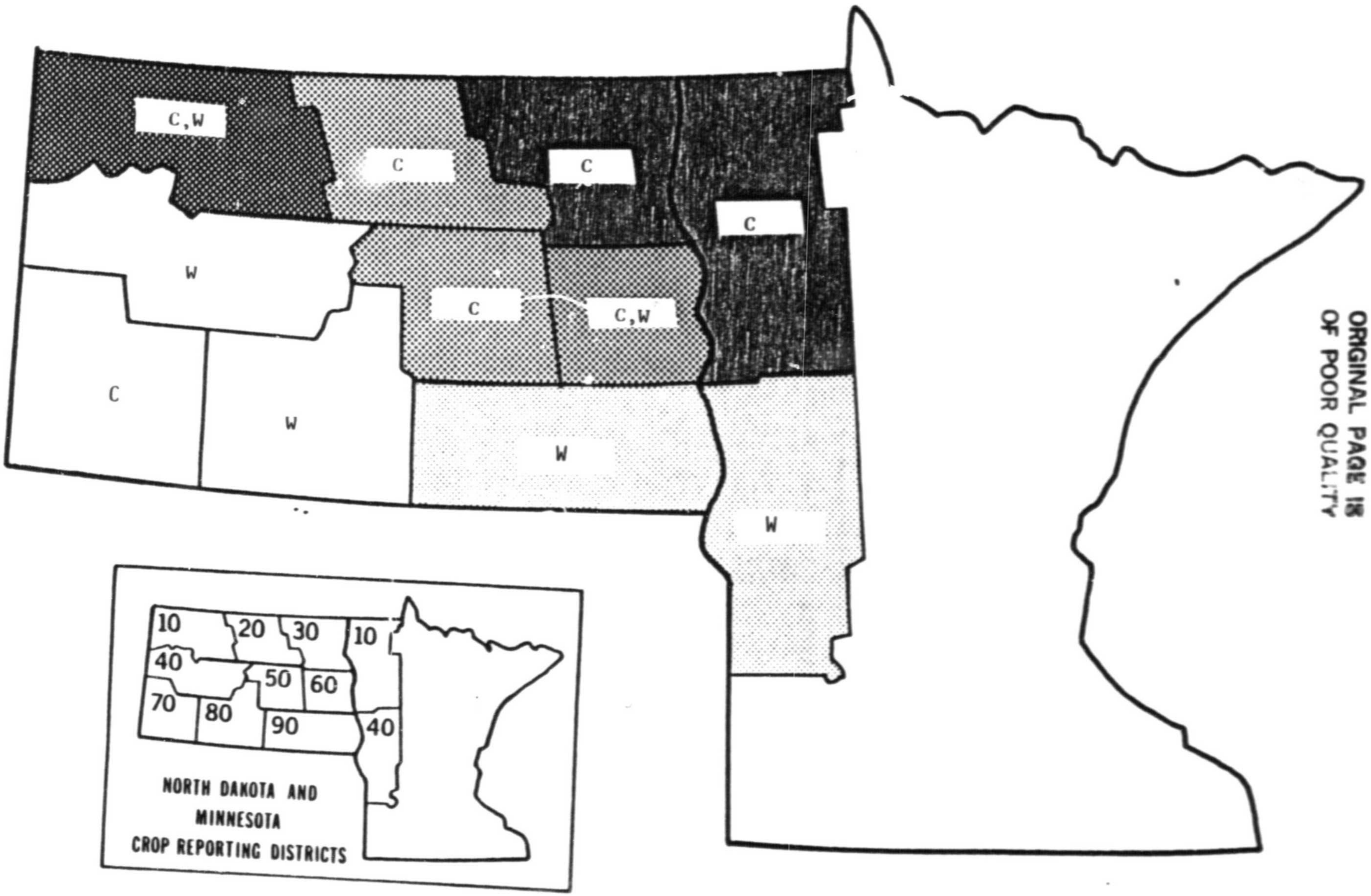


Figure 9. Letter indicates the model for spring wheat with the largest percentage of test years (1970- 1979) having agreement in the direction of change from the previous three year average between predicted and actual yields (C = CEAS, W = Williams-type, S = Strawman).

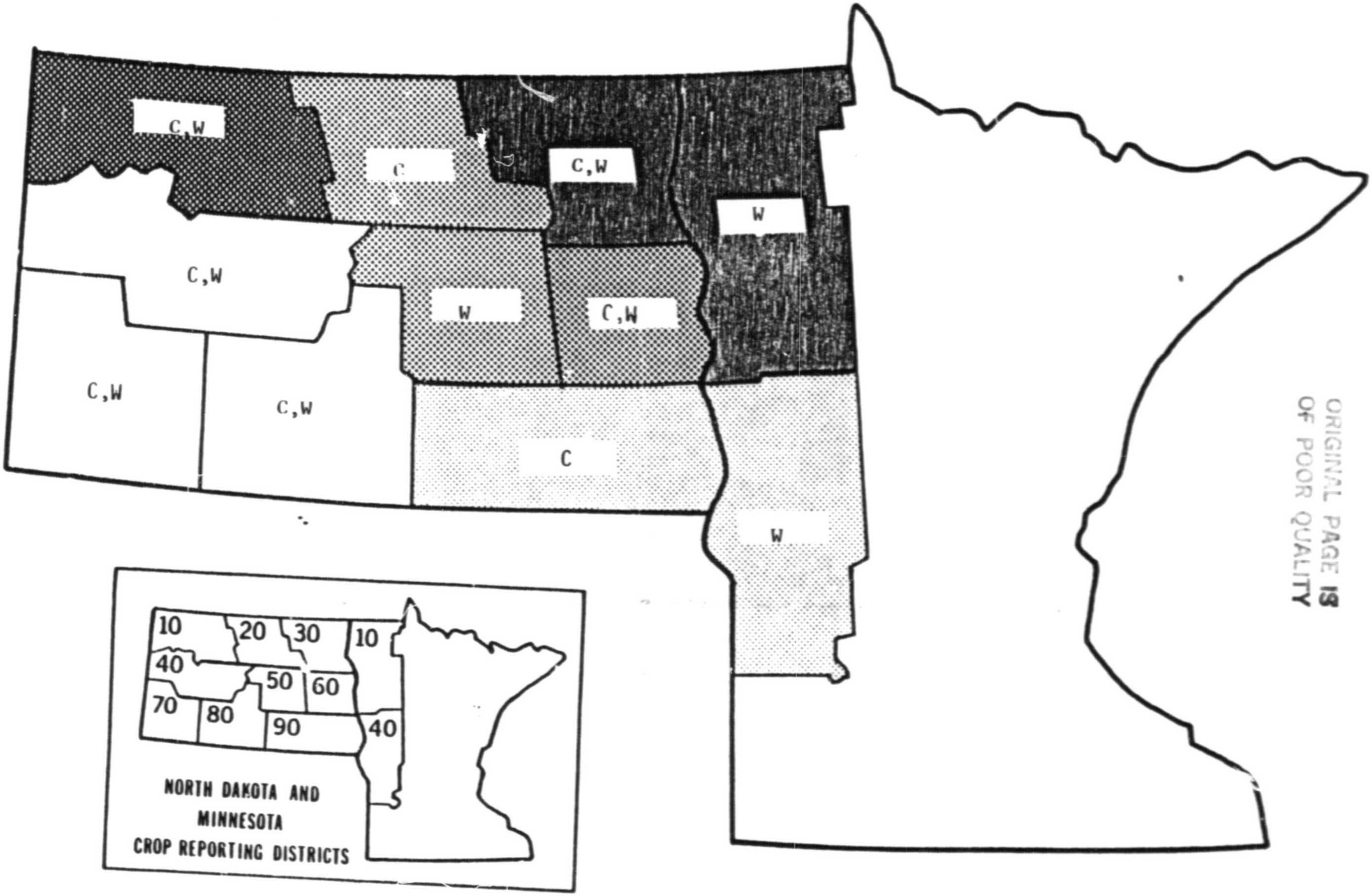
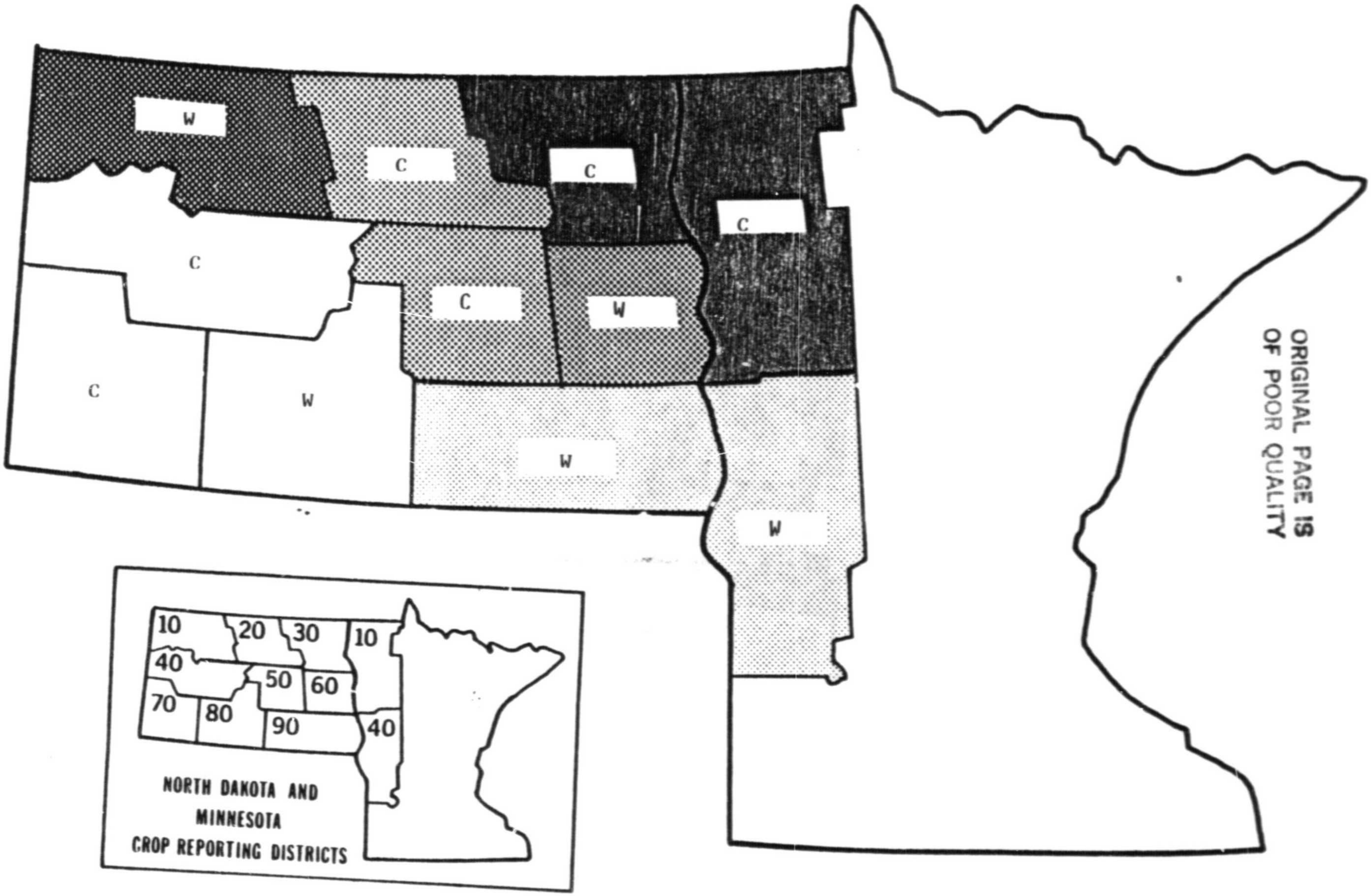


Figure 10. Letter indicates the model for spring wheat with the largest correlation coefficient between actual and predicted yields over the test years 1970-1979 (C = CEAS, W = Williams-type, S = Strawman).



ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 11
MODEL COMPARISON BASED ON
PAIRED-SAMPLE STATISTICAL TESTS
STRAWMAN MODEL WITH CEAS MODEL
(*=P<.10, **=P<.05, ***=P<.01)

TREND AND MONTHLY WEATHER DATA MODELS
SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

		PARAMETRIC T-TEST			NONPARAMETRIC RANK TEST		
		AVERAGE |D| MODEL		DIFFERENCE OF AVERAGES	% SMALLER |D| MODEL		DIFFERENCE OF PERCENTAGE
STATE	CRD	STRMAN	CEAS		STRMAN	CEAS	
N.DAKOTA	10	2.9	1.6	1.3	20	80	60
	20	3.1	1.2	1.9 **	20	80	60 ***
	30	3.0	1.3	1.7 **	20	80	60 **
	40	2.9	1.0	1.9 **	20	80	60 ***
	50	3.5	2.2	1.3	40	60	20 *
	60	3.0	1.4	1.6 **	30	70	40 **
	70	2.7	1.5	1.1	40	60	20
	80	3.1	2.3	0.8	40	60	20
	90	2.8	2.0	0.8	30	70	40 *
STATE MODEL		2.8	1.0	1.8 **	10	90	80 ***
CRDS AGGR.		2.8	1.0	1.9 ***	10	90	80 ***
MINNESOTA	10	2.3	1.2	1.1 *	30	70	40 *
	40	4.3	3.8	0.5	30	60	30
STATE MODEL		2.6	1.7	0.9	40	60	20 *
CRDS AGGR.		2.5	2.0	0.5	30	70	40
REGION							
CRDS AGGR.		2.5	0.9	1.6 **	10	90	80 **
STATES AGGR.		2.4	0.9	1.5 **	20	80	60 **

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 12
MODEL COMPARISON BASED ON
PAIRED-SAMPLE STATISTICAL TESTS
STRAWMAN MODEL WITH WILLIAMS MODEL
(*=P<.10, **=P<.05, ***=P<.01)

TREND AND MONTHLY WEATHER DATA MODELS
SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

		PARAMETRIC T-TEST			NONPARAMETRIC RANK TEST		
		AVERAGE |D| MODEL		DIFFERENCE OF AVERAGES	% SMALLER |D| MODEL		DIFFERENCE OF PERCENTAGE
STATE	CRD	STRMAN	WILIAM		STRMAN	WILIAM	
N.DAKOTA	10	2.9	1.3	1.6	30	60	30 *
	20	3.1	1.6	1.5	30	70	40 *
	30	3.0	1.4	1.6 *	20	70	50 **
	40	2.9	1.2	1.7 **	30	70	40 **
	50	3.5	1.8	1.7 *	20	80	60 *
	60	3.0	1.4	1.6 *	30	70	40 **
	70	2.7	1.5	1.1	30	70	40
	80	3.1	2.2	0.9	20	80	60 *
	90	2.8	1.7	1.0	40	50	20
STATE MODEL		2.8	1.3	1.5 **	10	80	70 ***
CRDS AGGR.		2.9	1.1	1.8 **	20	80	60 ***
MINNESOTA	10	2.3	2.5	0.2	60	40	20
	40	4.3	2.8	1.5 *	30	70	40 *
STATE MODEL		2.6	1.8	0.8	30	70	40
CRDS AGGR.		2.5	2.1	0.4	40	60	20
REGION							
CRDS AGGR.		2.5	1.2	1.3 *	30	50	20 *
STATES AGGR.		2.4	1.0	1.4 **	30	70	40 **

TABLE 13
MODEL COMPARISON BASED ON
PAIRED-SAMPLE STATISTICAL TESTS
WILLIAMS MODEL WITH CEAS MODEL
(*=P<.10, **=P<.05, ***=P<.01)

TREND AND MONTHLY WEATHER DATA MODELS
SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

		PARAMETRIC T-TEST			NONPARAMETRIC RANK TEST		
		AVERAGE |D| MODEL		DIFFERENCE OF	% SMALLER |D| MODEL		DIFFERENCE OF
STATE	CRD	WILIAM	CEAS	AVERAGES	WILIAM	CEAS	PERCENTAGE
N.DAKOTA	10	1.3	1.6	0.3	60	40	20
	20	1.6	1.2	0.4	30	60	30
	30	1.4	1.3	0.1	30	60	30
	40	1.2	1.0	0.2	40	60	20
	50	1.8	2.2	0.4	70	30	40
	60	1.4	1.4	0.0	50	50	0
	70	1.5	1.5	0.0	50	50	0
	80	2.2	2.3	0.1	50	40	10
	90	1.7	2.0	0.3	50	50	0
STATE MODEL		1.3	1.0	0.2	20	70	50
CRDS AGGR.		1.1	1.0	0.1	40	50	10
MINNESOTA	10	2.5	1.2	1.3 *	30	70	40 **
	40	2.8	3.8	1.0	70	30	40
STATE MODEL		1.8	1.7	0.1	50	50	0
CRDS AGGR.		2.1	2.0	0.1	60	40	20
REGION							
CRDS AGGR.		1.2	0.9	0.3	50	50	0
STATES AGGR.		1.0	0.9	0.1	40	60	20

Figure 11. Comparison of Williams-type (W) and Strawman (S) models to predict spring wheat yields using parametric t-test based on average of $|d| = |\hat{Y} - Y|$ for 1970-1979. Letters indicate model with smaller $|d|$. Stars indicate base of significance as described in Table 11.

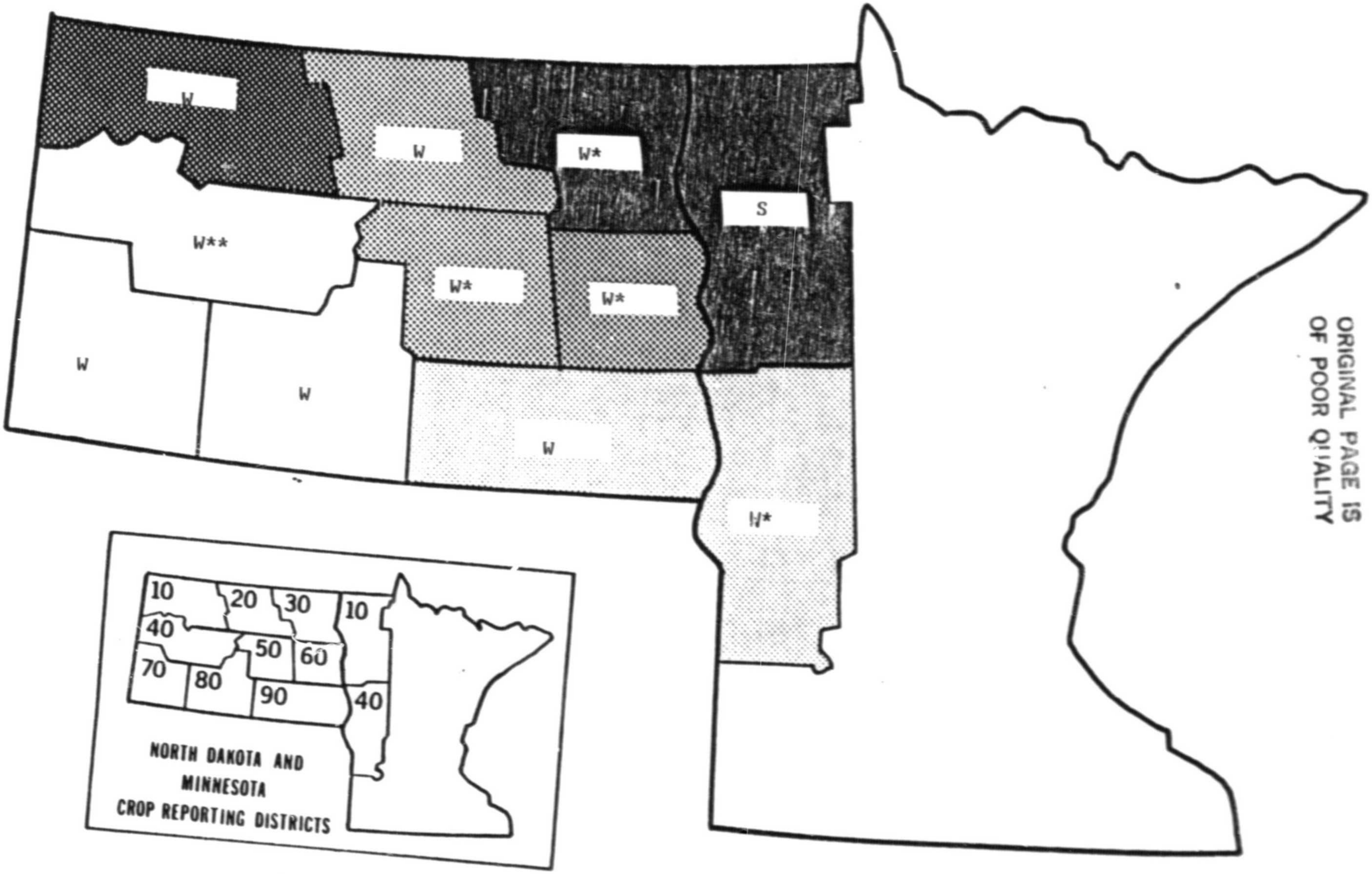


Figure 12. Comparison of CEAS (C) and Strawman (S) models to predict spring wheat yields using parametric t-test based on average of $|d| = |\hat{Y} - Y|$ for 1970-1979. Letter indicates model with smaller $|d|$. Stars indicate base of significance as described in Table 12.

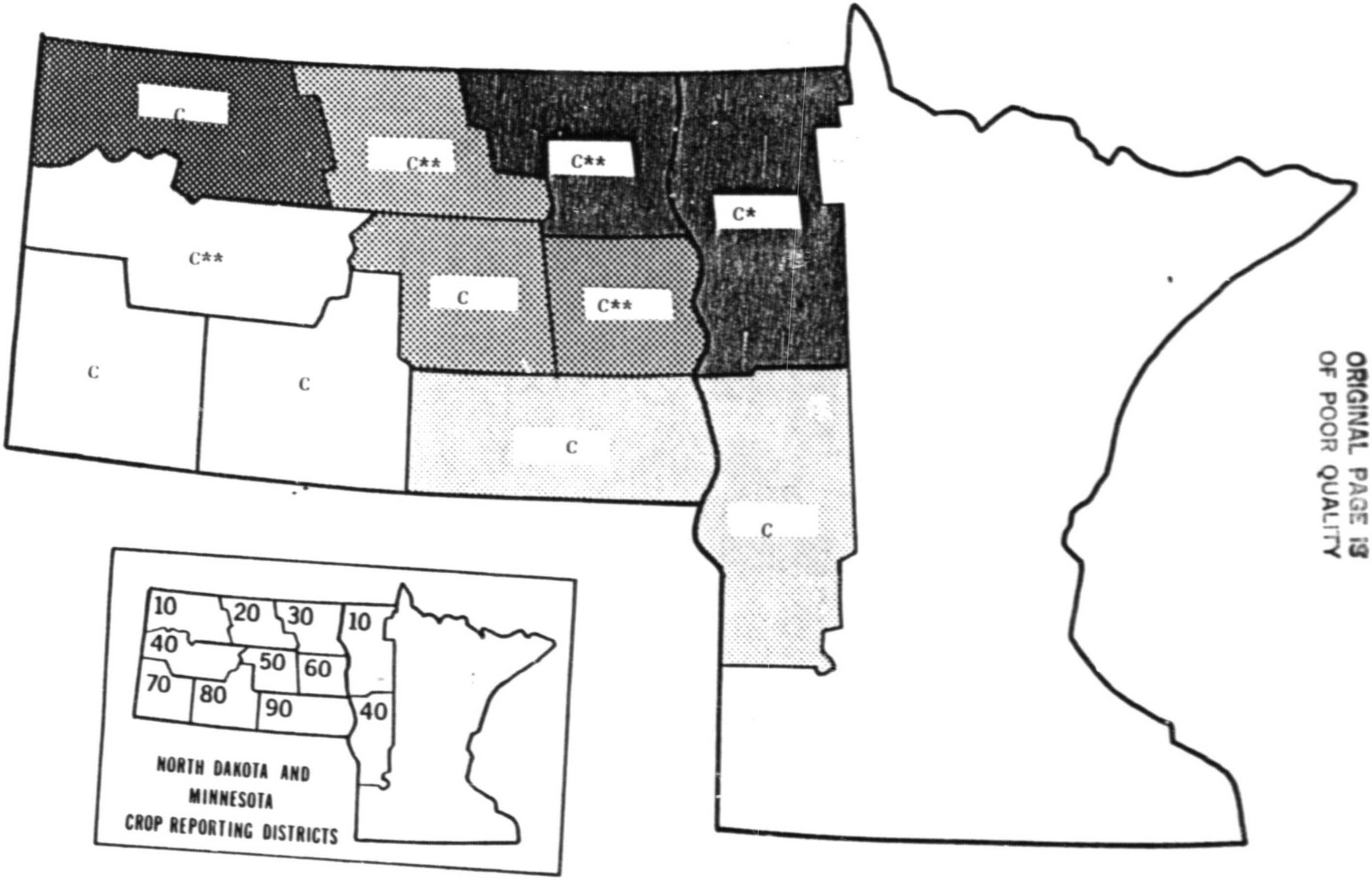


Figure 13. Comparison of CEAS (C) and Williams-type (W) models to predict spring wheat yields using parametric t-test based on average of $|d| = |\hat{Y} - Y|$ for 1970-1979. Letter indicates model with smaller $|d|$. Stars indicate level of significance as described in Table 13.

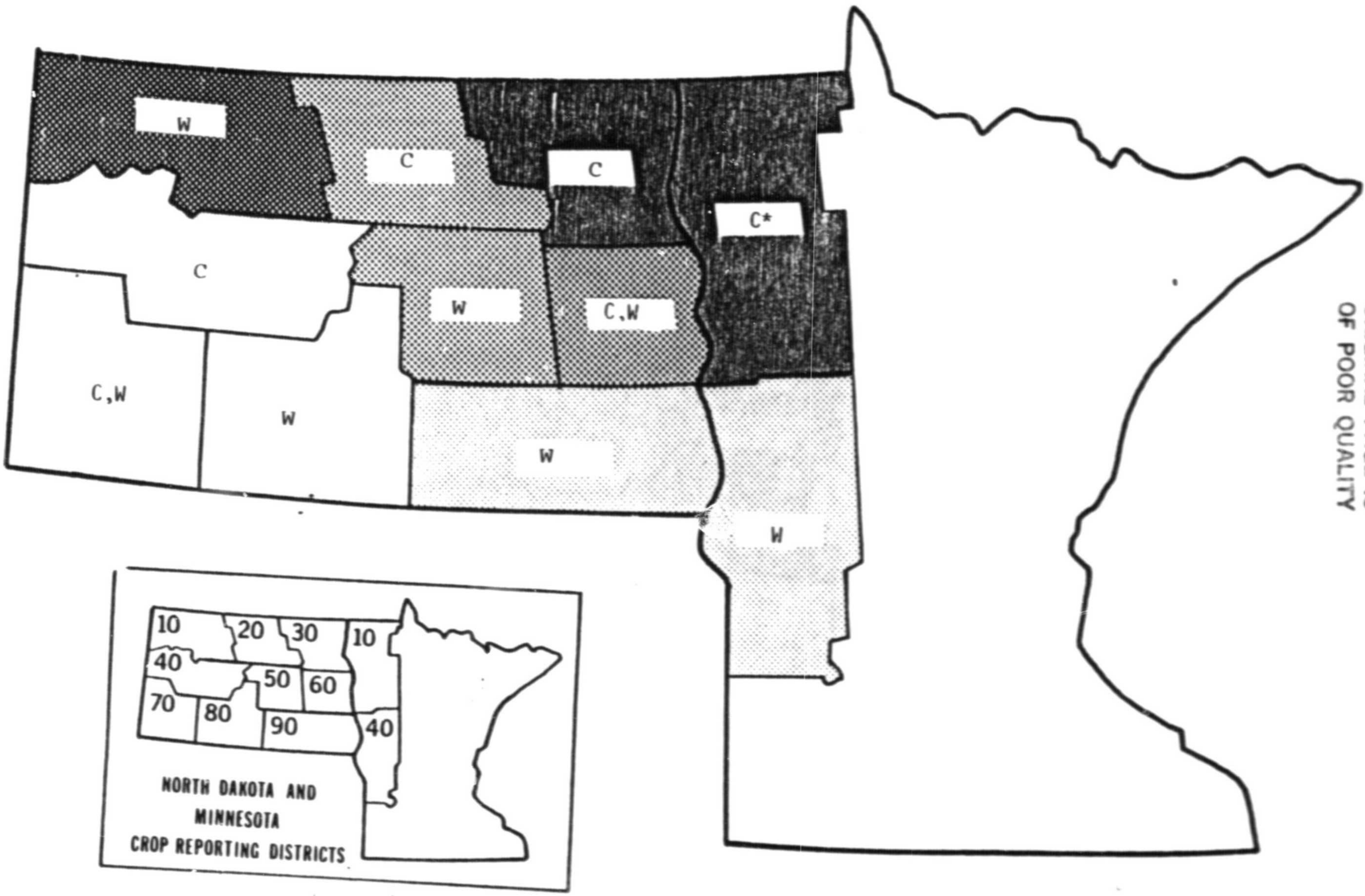
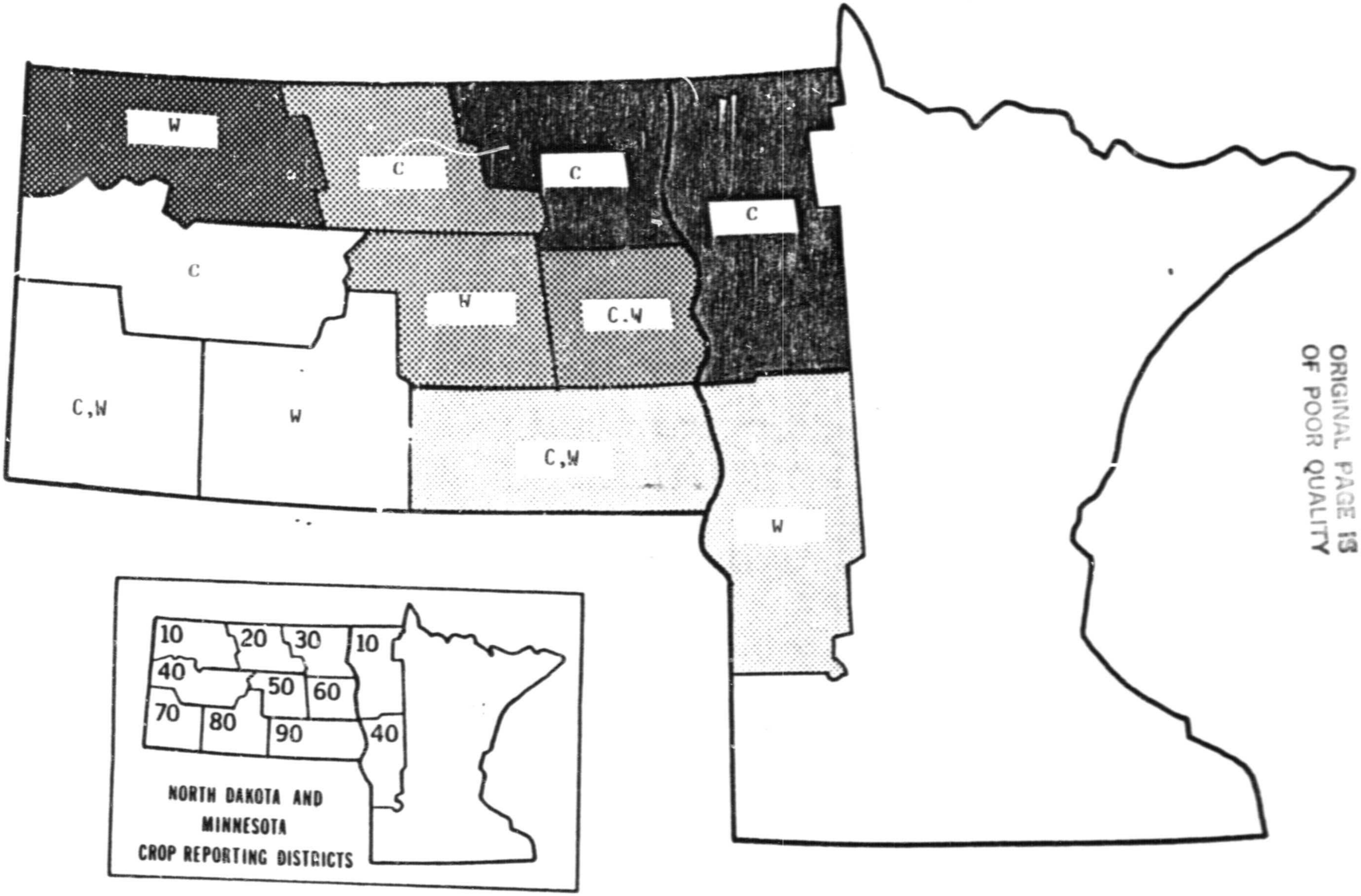


Figure 14. Comparison of CEAS (C) and Williams-type (W) models to predict spring wheat yields using nonparametric rank test based on percent of test years (1970-1979) with smaller absolute value of relative difference. Letter indicates model with larger percent. Stars indicate level of significance as described in Table 13.



ORIGINAL PAGE IS
OF POOR QUALITY

TABLE 14
MODEL COMPARISON OF THE
CURRENT INDICATION OF MODELED YIELD RELIABILITY
BASED ON THE CORRELATION COEFFICIENT BETWEEN
BASE PERIOD PREDICTED AND TEST YEAR ACTUAL ACCURACY

TREND AND MONTHLY WEATHER DATA MODELS
SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

		MODEL					
		STRAWMAN		WILLIAMS		CEAS	
STATE	CRD	R	RANK	R	RANK	R	RANK
N.DAKOTA	10	0.36	(1)	-0.04	(2)	-0.20	(3)
	20	0.27	(1)	-0.38	(3)	-0.12	(2)
	30	0.11	(2)	0.39	(1)	-0.04	(3)
	40	-0.02	(3)	-0.01	(2)	0.04	(1)
	50	0.05	(2)	-0.07	(3)	0.45	(1)
	60	0.25	(1)	-0.01	(2)	-0.20	(3)
	70	-0.04	(2)	0.05	(1)	-0.19	(3)
	80	-0.13	(3)	0.02	(1)	0.02	(1)
	90	-0.32	(3)	0.22	(2)	0.70	(1)
STATE MODEL		0.25	(1)	0.10	(2)	-0.17	(3)
MINNESOTA	10	-0.54	(3)	-0.50	(2)	0.05	(1)
	40	0.21	(1)	-0.11	(3)	0.14	(2)
STATE MODEL		-0.09	(1)	-0.73	(2)	-0.91	(3)

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SPRING WHEAT YIELDS IN
NORTH DAKOTA AND MINNESOTA
COMPARING TREND AND MONTHLY WEATHER DATA MODELS
STMAN=STRAWMAN I WILMS=WILLIAMS TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	WILMS	CEAS	D= PREDICTED-ACTUAL STMAN	WILMS	CEAS
N.DAKOTA	10	1970	16.2	18.1	15.5	17.0	1.9	-0.7	0.8
		1971	20.0	18.5	17.8	20.5	-1.5	-2.2	0.5
		1972	19.9	19.4	21.2	24.4	-0.5	1.3	4.5
		1973	20.1	20.2	16.5	16.7	0.1	-3.6	-3.4
		1974	14.8	21.2	15.6	15.8	6.4	0.8	1.0
		1975	16.7	20.7	16.2	17.5	4.0	-0.5	0.8
		1976	17.6	20.4	17.3	17.6	2.8	-0.3	0.0
		1977	16.5	20.3	15.9	14.5	3.8	-0.6	-2.0
		1978	21.9	19.7	19.7	20.4	-2.2	-2.2	-1.5
		1979	14.5	20.5	15.3	15.7	6.0	0.8	1.2
	20	1970	14.9	18.3	14.5	16.9	3.4	-0.4	2.0
		1971	20.7	18.6	17.5	19.4	-2.1	-3.2	-1.3
		1972	19.2	19.7	19.2	19.2	0.5	0.0	0.0
		1973	19.8	20.3	16.6	19.2	0.5	-3.2	-0.6
		1974	12.9	21.1	15.9	15.6	8.2	3.0	2.7
		1975	16.4	20.5	15.0	16.1	4.1	-1.4	-0.3
		1976	16.4	20.3	16.4	18.0	3.9	0.0	1.6
		1977	14.8	19.9	15.7	16.5	5.1	0.9	1.7
		1978	19.7	18.9	17.9	18.3	-0.8	-1.8	-1.4
		1979	16.6	19.2	14.5	17.3	2.6	-2.1	0.7
	30	1970	18.9	22.1	18.0	18.7	3.2	-0.9	-0.2
		1971	24.1	22.5	22.1	23.0	-1.6	-2.0	-1.1
		1972	21.0	23.5	22.2	22.8	2.5	1.2	1.8
		1973	20.4	23.9	20.6	21.5	3.5	0.2	1.1
		1974	15.3	24.2	18.6	18.0	8.9	3.3	2.7
		1975	20.9	23.3	18.7	19.1	2.4	-2.2	-1.8
		1976	19.9	23.4	19.8	20.0	3.5	-0.1	0.1
		1977	20.3	22.8	20.7	20.5	2.5	0.4	0.2
		1978	22.3	22.1	22.1	21.4	-0.2	-0.2	-0.9
		1979	23.8	22.1	20.0	20.8	-1.7	-3.8	-3.0
	40	1970	14.2	16.8	15.5	14.6	2.6	1.3	0.4
		1971	18.6	17.1	16.5	16.5	-1.5	-2.1	-2.1
		1972	20.2	18.2	20.4	20.7	-2.0	0.2	0.5
		1973	17.7	19.1	15.7	16.7	1.4	-2.0	-1.0
		1974	11.6	19.7	14.4	12.8	8.1	2.8	1.2
		1975	16.5	19.0	15.8	16.1	2.5	-0.7	-0.4
		1976	17.3	18.9	15.6	15.4	1.6	-1.7	-1.9
		1977	15.4	18.8	15.4	13.9	3.4	0.0	-1.5
		1978	20.1	18.3	19.2	19.8	-1.8	-0.9	-0.3
		1979	15.2	18.9	15.1	14.4	3.7	-0.1	-0.8

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SPRING WHEAT YIELDS IN
NORTH DAKOTA AND MINNESOTA
COMPARING TREND AND MONTHLY WEATHER DATA MODELS
STMAN=STRAWMAN I WILMS=WILLIAMS TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	WILMS	CEAS	D= PREDICTED-ACTUAL STMAN	WILMS	CEAS
N.DAKOTA	50	1970	15.9	18.3	13.7	13.0	2.4	-2.2	-2.9
		1971	22.5	18.8	17.0	18.1	-3.7	-5.5	-4.4
		1972	18.2	20.3	17.8	19.8	2.1	-0.4	1.6
		1973	15.0	20.6	14.4	17.4	5.6	-0.6	2.4
		1974	12.0	20.3	15.9	14.5	8.3	3.9	2.5
		1975	17.1	19.6	15.9	15.8	2.5	-1.2	-1.3
		1976	14.7	19.5	14.0	15.5	4.8	-0.7	0.8
		1977	14.4	18.8	15.2	10.9	4.4	0.8	-3.5
		1978	19.2	17.9	18.1	17.5	-1.3	-1.1	-1.7
		1979	17.9	18.2	15.8	16.6	0.3	-2.1	-1.3
	60	1970	18.0	21.9	17.6	17.9	3.9	-0.4	-0.1
		1971	24.5	22.1	21.2	22.2	-2.4	-3.3	-2.3
		1972	20.6	23.3	21.6	22.0	2.7	1.0	1.4
		1973	20.2	23.5	19.3	20.7	3.3	-0.9	0.5
		1974	15.7	23.6	17.4	18.2	7.9	1.7	2.5
		1975	19.4	22.9	18.6	18.3	3.5	-0.8	-1.1
		1976	19.3	22.4	18.3	19.0	3.1	-1.0	-0.3
		1977	20.6	21.8	20.0	19.2	1.2	-0.6	-1.4
		1978	22.8	21.5	21.1	20.5	-1.3	-1.7	-2.2
		1979	22.6	21.5	19.5	20.3	-1.1	-3.1	-2.3
	70	1970	13.8	15.9	15.4	14.5	2.1	1.6	0.7
		1971	18.6	16.2	17.5	16.8	-2.4	-1.1	-1.8
		1972	18.7	17.6	21.1	20.0	-1.1	2.4	1.3
		1973	19.1	16.3	16.1	15.2	-2.8	-3.0	-3.9
		1974	15.2	19.1	14.2	13.7	3.9	-1.0	-1.5
		1975	15.4	19.3	16.0	16.6	3.9	0.6	1.2
		1976	16.8	19.1	14.9	14.1	2.3	-1.9	-2.7
		1977	14.1	19.1	15.2	13.3	5.0	1.1	-0.8
		1978	17.8	18.4	19.8	19.1	0.6	2.0	1.3
		1979	14.1	18.6	14.9	13.9	4.5	0.8	-0.2
	80	1970	11.1	14.5	13.4	14.4	3.4	2.3	3.3
		1971	17.8	14.6	16.3	14.1	-3.2	-1.5	-3.7
		1972	16.0	15.8	18.4	17.8	-0.2	2.4	1.8
		1973	13.2	16.2	13.9	11.8	3.0	0.7	-1.4
		1974	8.7	16.2	12.8	14.7	7.5	4.1	6.0
		1975	14.2	15.5	15.3	16.1	1.3	1.1	1.9
		1976	11.1	15.6	13.1	11.3	4.5	2.0	0.2
		1977	11.0	14.9	14.1	10.8	3.9	3.1	-0.2
		1978	15.6	14.2	18.6	18.6	-1.4	3.0	3.0
		1979	12.2	14.6	14.0	11.3	2.4	1.8	-0.9

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SPRING WHEAT YIELDS IN
NORTH DAKOTA AND MINNESOTA
COMPARING TREND AND MONTHLY WEATHER DATA MODELS
STMAN=STRAWMAN I WILMS=WILLIAMS TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	WILMS	CEAS	D= PREDICTED-ACTUAL STMAN	WILMS	CEAS
N.DAKOTA	90	1970	14.3	16.3	13.7	13.0	2.0	-0.6	-1.3
		1971	21.5	16.7	17.3	18.5	-4.8	-4.2	-3.0
		1972	17.3	18.3	19.0	21.7	1.0	1.7	4.4
		1973	15.9	18.7	13.9	17.7	2.8	-2.0	1.8
		1974	12.9	18.9	15.7	17.7	6.0	2.8	4.8
		1975	15.3	18.8	16.8	16.1	3.5	1.5	0.8
		1976	11.9	18.6	12.6	14.1	6.7	0.7	2.2
		1977	17.1	17.6	16.1	16.0	0.5	-1.0	-1.1
		1978	17.3	17.5	19.3	17.5	0.2	2.0	0.2
		1979	17.3	17.5	16.5	17.4	0.2	-0.8	0.1
STATE MODEL		1970	15.8	18.5	16.3	15.8	2.7	0.5	0.0
		1971	21.4	18.9	19.0	19.4	-2.5	-2.4	-2.0
		1972	19.4	20.1	20.9	19.1	0.7	1.5	-0.3
		1973	18.5	20.6	16.4	17.2	2.1	-2.1	-1.3
		1974	13.7	21.1	16.9	15.7	7.4	3.2	2.0
		1975	17.4	20.5	16.7	16.7	3.1	-0.7	-0.7
		1976	16.6	20.4	16.1	16.8	3.8	-0.5	0.2
		1977	15.7	18.9	17.3	15.5	3.2	0.6	-0.2
		1978	20.1	19.3	20.2	18.1	-0.8	0.1	-2.0
		1979	17.7	19.5	16.6	17.2	1.9	-1.1	-0.5
CRDS AGGR.		1970	15.8	18.6	15.6	16.1	2.8	-0.2	0.3
		1971	21.4	19.0	18.6	19.5	-2.4	-2.8	-1.9
		1972	19.4	20.2	20.4	21.5	0.8	1.0	2.1
		1973	18.5	20.7	16.9	18.1	2.2	-1.6	-0.4
		1974	13.7	21.1	16.1	16.1	7.4	2.4	2.4
		1975	17.4	20.5	16.7	17.1	3.1	-0.7	-0.3
		1976	16.6	20.4	16.3	16.8	3.8	-0.3	0.2
		1977	15.7	18.9	17.0	15.0	3.2	0.3	-0.7
		1978	20.1	19.1	19.7	19.5	-1.0	-0.4	-0.6
		1979	17.7	19.5	16.5	16.9	1.8	-1.2	-0.8

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SPRING WHEAT YIELDS IN
NORTH DAKOTA AND MINNESOTA
COMPARING TREND AND MONTHLY WEATHER DATA MODELS
STMAN=STRAWMAN 1 WILMS=WILLIAMS TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	WILMS	CEAS	D= PREDICTED-ACTUAL STMAN	WILMS	CEAS
MINNESOTA	10	1970	18.5	21.6	18.7	19.9	3.1	0.2	1.4
		1971	26.9	21.7	22.4	26.2	-5.2	-4.5	-0.7
		1972	24.2	23.2	23.3	25.7	-1.0	-0.9	1.5
		1973	26.0	23.9	22.1	24.6	-2.1	-3.9	-1.4
		1974	18.6	24.8	18.7	20.7	6.2	0.1	2.1
		1975	22.7	24.6	20.6	23.2	1.9	-2.1	0.5
		1976	24.6	24.5	21.1	25.6	-0.1	-3.5	1.0
		1977	23.6	24.9	21.4	24.4	1.3	-2.2	0.8
		1978	26.6	24.7	22.9	27.1	-1.9	-3.7	0.5
		1979	24.9	25.2	21.2	26.5	0.3	-3.7	1.6
	40	1970	18.4	19.4	17.9	20.0	1.0	-0.5	1.6
		1971	23.3	20.0	20.2	22.9	-3.3	-3.1	-0.4
		1972	17.3	21.4	18.6	21.4	4.1	1.3	4.1
		1973	26.7	21.4	20.2	22.2	-5.3	-6.5	-4.5
		1974	19.4	22.9	18.4	22.2	3.5	-1.0	2.8
		1975	18.2	23.2	18.7	22.3	5.0	0.5	4.1
		1976	14.9	22.8	16.9	19.3	7.9	2.0	4.4
		1977	28.6	21.5	20.1	23.1	-7.1	-8.5	-5.5
		1978	17.3	22.7	19.8	24.5	5.4	2.5	7.2
		1979	21.6	22.0	19.6	24.6	0.4	-2.0	3.0
STATE MODEL		1970	18.6	21.0	19.1	19.2	2.4	0.5	0.6
		1971	25.6	21.2	23.7	24.2	-4.4	-1.9	-1.4
		1972	22.2	22.6	23.7	22.9	0.4	1.5	0.7
		1973	26.2	23.1	24.7	24.5	-3.1	-1.5	-1.7
		1974	19.5	24.2	21.2	20.9	4.7	1.7	1.4
		1975	20.9	24.1	23.0	22.0	3.2	2.1	1.1
		1976	21.8	23.9	23.5	24.4	2.1	1.7	2.6
		1977	26.8	23.8	24.8	24.4	-3.0	-2.0	-2.4
		1978	22.7	24.4	25.6	25.8	1.7	2.9	3.1
		1979	23.6	24.3	25.9	25.5	0.7	2.3	1.9
CRDS AGGR.		1970	18.5	20.9	18.4	19.9	2.4	-0.1	1.4
		1971	25.9	21.2	21.8	25.3	-4.7	-4.1	-0.6
		1972	22.3	22.7	22.0	24.5	0.4	-0.3	2.2
		1973	26.3	23.1	21.5	23.8	-3.2	-4.8	-2.5
		1974	18.9	24.1	18.6	21.3	5.2	-0.3	2.4
		1975	20.9	24.0	19.9	22.9	3.1	-1.0	2.0
		1976	20.9	23.8	19.5	23.2	2.9	-1.4	2.3
		1977	25.5	23.6	20.9	23.9	-1.9	-4.6	-1.6
		1978	23.3	24.0	21.8	26.2	0.7	-1.5	2.9
		1979	23.8	24.2	20.7	25.9	0.4	-3.1	2.1

ORIGINAL PAGE IS
OF POOR QUALITY

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SPRING WHEAT YIELDS IN
NORTH DAKOTA AND MINNESOTA
COMPARING TREND AND MONTHLY WEATHER DATA MODELS
STMAN=STRAWMAN 1 WILMS=WILLIAMS TYPE CEAS=CEAS MODEL

STATE	CRD	YEAR	ACTUAL YIELD (Q/H)	PREDICTED YIELD (Q/H) STMAN	WILMS	CEAS	D= PREDICTED-ACTUAL STMAN	WILMS	CEAS
REGION	CRDS AGGR.	1970	16.1	18.9	15.9	16.5	2.8	-0.2	0.4
		1971	22.0	19.3	19.1	20.4	-2.7	-2.9	-1.6
		1972	19.9	20.6	20.6	22.0	0.7	0.7	2.1
		1973	19.9	21.1	17.7	19.1	1.2	-2.2	-0.8
		1974	14.7	21.7	16.5	17.1	7.0	1.8	2.4
		1975	18.1	21.2	17.3	18.2	3.1	-0.8	0.1
		1976	17.5	21.1	17.0	18.2	3.6	-0.5	0.7
		1977	18.7	20.7	17.9	17.8	2.0	-0.8	-0.9
		1978	20.7	20.1	20.1	20.8	-0.6	-0.6	0.1
		1979	18.9	20.4	17.3	18.7	1.5	-1.6	-0.2
STATES AGGR.		1970	16.2	18.8	15.6	16.2	2.6	0.4	0.0
		1971	22.0	19.2	19.7	20.1	-2.8	-2.3	-1.9
		1972	19.9	20.5	21.4	19.7	0.6	1.5	-0.2
		1973	19.9	21.1	17.9	18.6	1.2	-2.0	-1.3
		1974	14.9	21.8	17.8	16.8	5.9	2.9	1.9
		1975	18.2	21.3	18.1	17.8	3.1	-0.1	-0.4
		1976	17.9	21.3	18.0	18.7	3.4	0.1	0.8
		1977	19.3	20.9	19.3	17.8	1.6	0.0	-1.5
		1978	20.7	20.4	21.4	19.8	-0.3	0.7	-0.9
		1979	18.9	20.6	18.6	18.9	1.7	-0.3	0.0

NASA-JSC